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Uncertainty analysis of runoff estimates from runoff-depth contour maps produced by five automated procedures for the northeastern United States

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AN ABSTRACT OF THE THESIS OF Gary D. Bishop for the Master of Science in Geography presented September 24, 1991.

Title: Uncertainty Analysis of Runoff Estimates from Runoff-Depth Contour Maps Produced by Five Automated Procedures for the Northeastern United States.

APPROVED BY THE MEMBERS OF THE THESIS COMMITTEE:

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Roy W. Koch

Maps of runoff-depth have been found to be useful tools in a variety of water resource applications. Producing such maps can be a challenging and expensive task. One of the standard methods of producing these maps is to use a manual procedure based on gaged runoff data, topographic and past runoff-depth maps, and the expert opinion of hydrologists.

This thesis examined five new automated procedures for producing runoff-depth contour maps to see if the maps produced by these procedures had similar accuracy and characteristics when compared to the manual procedure. An uncertainty analysis was used to determine the accuracy of the automated procedure maps by withholding gaged runoff data from the creation of the contour maps and then interpolating estimated runoff back to these sites from the maps produced. Subtracting gaged runoff from estimated runoff produced interpolation error values. The mean interpolation error was used to define the accuracy of each map and was then compared to a similar study by Rochelle, *et al.*, (1989) conducted on a manual procedure map.

This thesis found that two automated procedures, one based on estimating runoff with mean regional water-year runoff-to-precipitation ratios and the other on a regression formula based on long-term climatic data used to predict water-year 1984 runoff, had the lowest mean interpolation errors. These two procedures produce the most accurate maps on a regional basis of the five tested and compare favorably in regards to accuracy and lack of bias to the manual procedure. These results indicate that simple automated procedures can produce runoff-depth contour maps with regional accuracies roughly equivalent to those produced by the manual procedure.

UNCERTAINTY ANALYSIS OF RUNOFF ESTIMATES FROM RUNOFF-DEPTH CONTOUR MAPS PRODUCED BY FIVE AUTOMATED PROCEDURES FOR THE NORTHEASTERN UNITED STATES

by

GARY D. BISHOP

A thesis submitted in partial fulfillment of the
requirements for the degree of

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TO MY FATHER AND MOTHER

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CHAPTER I

INTRODUCTION

The mapping of the distribution of runoff (*i.e.* streamflow) is a task that has been pursued by American geographers and hydrologists since streams were first gaged in this country (Langbein, *et al.*, 1949). The task is made especially difficult by variations in vegetation, geology, land use, precipitation, and other factors over space (Sopper and Lull, 1970, USGS, 1984) which can cause sharp spatial variations in runoff (Rafter, 1903). Nevertheless, reliable runoff estimates are necessary to water resource planning and scientific studies (*e.g.* Solomon, *et al.*, 1968, Church, *et al.*, 1989) and much effort has been put into creating maps of runoff from which these estimates can be obtained. To show the pattern of runoff unbiased by the size of the watersheds involved, runoff is mapped as runoff-depth; that is, the volume of water that flows off the given area spread proportionately over that area in relation to a location's contribution to runoff (volume of runoff / watershed area) (Miller, *et al.*, 1962).

Geographers and hydrologists have utilized several methods to produce runoff-depth contour maps (Langbein, *et al.*, 1949, Thornthwaite, *et al.*, 1958, Solomon, *et al.*, 1968, Liebscher, 1972, Foyster, 1975, Krug, *et al.*, 1990) but the predominate method of mapping runoff is with manual methods (*e.g.* Krug, *et al.*, 1990). Automated methods to map runoff-depth have been developed (*e.g.* Solomon, *et al.*, 1968, Foyster, 1975), but none are widely used.

This thesis was based on work to find simple automated procedures that duplicate the accuracy of maps produced manually. The accuracy of five new automated procedures for producing water-year runoff-depth contour maps was examined using an uncertainty analysis. The time period considered was water-year 1984 (WY84) (*i.e.* October 1, 1983 to September 30, 1984) with the northeastern United States being the area of study (Figure 1). This time period and region were used because of the availability of a manually produced map for comparison. Major Land Resource Area's (MLRA's) (USDA, 1981) (Figure 1) were utilized for regionalization of certain parameters in some of the automated procedures. MLRA's were used because they were created using both physiographic and land use/cover parameters that can be important to runoff response (Woodruff and Hewlett, 1970, USDA, 1981). The procedures used linear interpolation from point values of runoff to create contours of runoff-depth. To increase the number of sites with runoff values used for interpolation in these procedures, WY84 gaged precipitation stations were used for estimating runoff (Figure 2). All of the procedures except the first listed below used estimated runoff. The five procedures to produce runoff-depth maps are:

1) GAGE84, which uses simple linear interpolation of WY84 gaged runoff data only,

2) MNLTET, which uses a water balance formula method utilizing mean regional evapotranspiration (ET), determined from long-term (*i.e.* average for 1951-80) precipitation, long-term runoff data, and a long-term runoff-depth

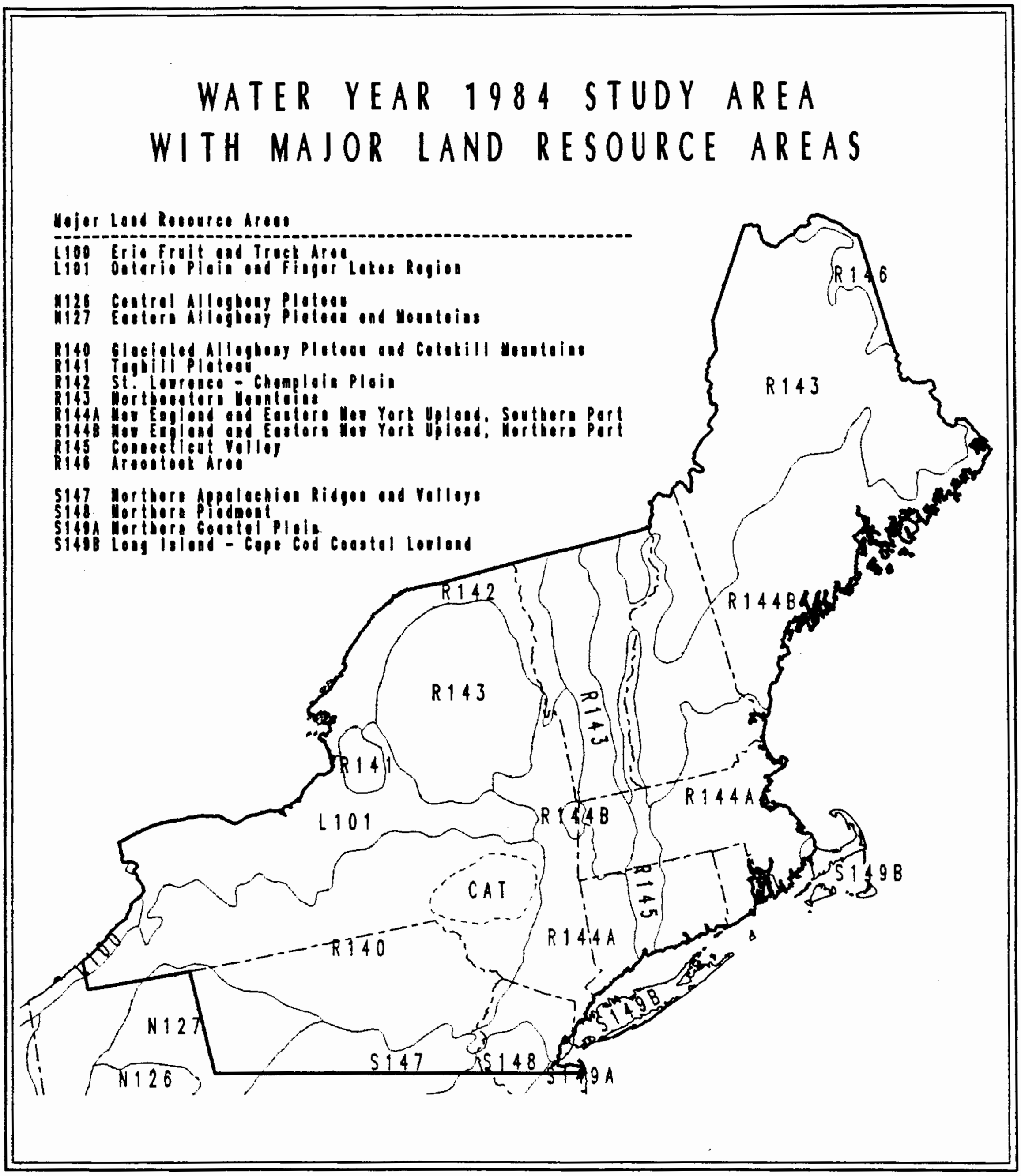


Figure 1. Study Area with Major Land Resource Areas. (MLRA source: USDA, 1981.)

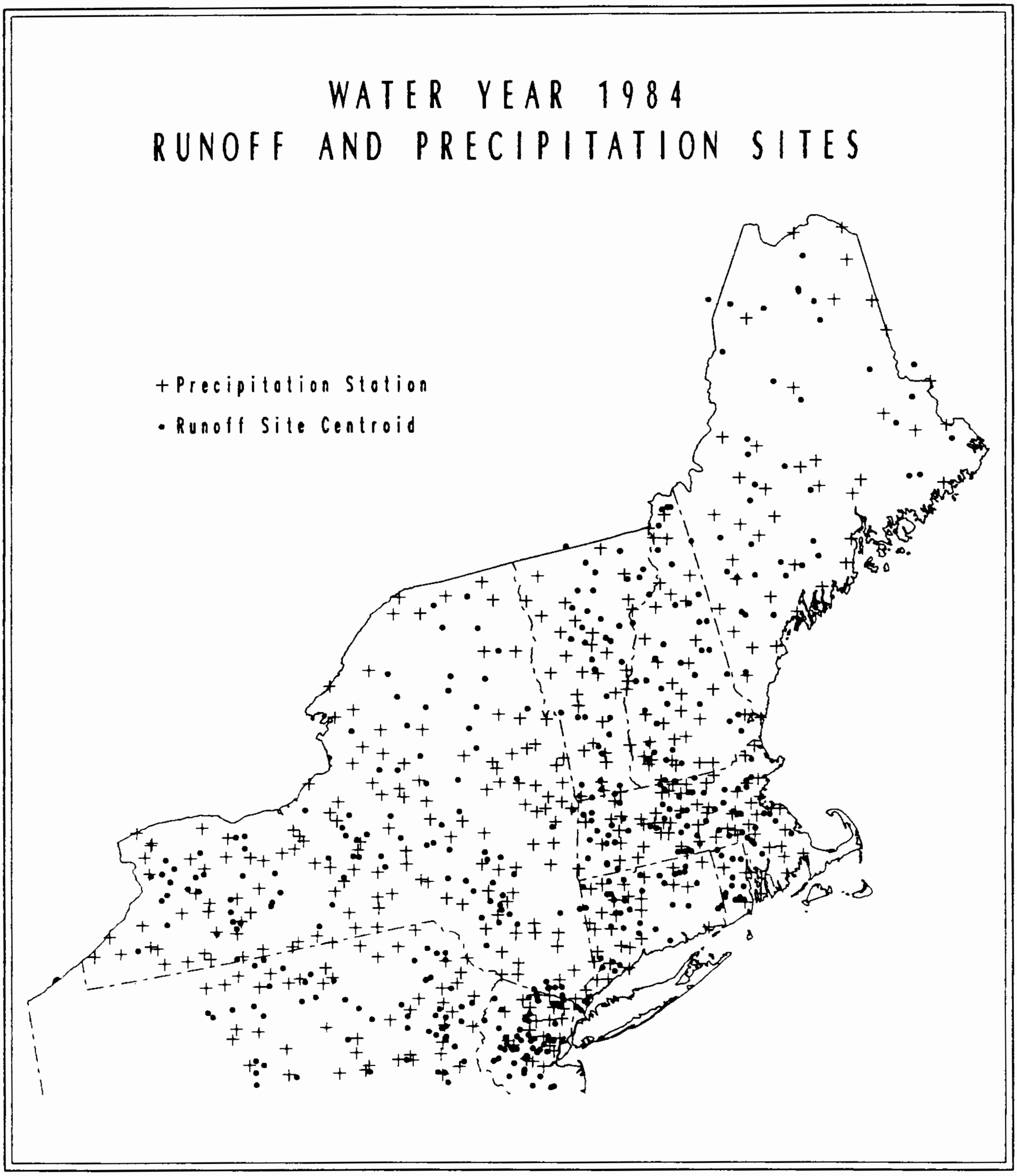


Figure 2. Water-Year 1984 USGS Gage Site Centroids and NCDC Precipitation Stations.

map, for Major Land Resource Areas (MLRA's) to estimate WY84 runoff at precipitation stations,

3) MNLTRP, which uses the ratio of mean regional long-term runoff-to-precipitation ratios (R/P) for MLRA's to calculate WY84 runoff at precipitation stations,

4) REG_R, which uses a regression formula based on long-term data to estimate runoff-depth at WY84 precipitation stations, and

5) MN84RP, which uses mean regional R/P determined from WY84 gaged precipitation and runoff data to calculate WY84 runoff at the precipitation stations.

Three of the procedures (MNLTET, MNLTRP, and REG_R) utilize information (*i.e.* expert opinion) incorporated in the generation of a long-term (1951-80) runoff depth contour map produced by the U.S. Geological Survey (USGS) (Krug, *et al.*, 1990). One of the questions examined in this thesis is whether utilizing this expert opinion will aide in producing an automated procedure map with an accuracy similar to the manual procedure map.

The five procedures examined are a subset of eight procedures developed in research conducted in conjunction with the U.S. Environmental Protection Agency's (EPA's) Direct/Delayed Response Project (DDRP). The automated procedures have the advantage, since they use computer algorithms, of being reproducible as well as being less expensive and time consuming than the manual method (Church, 1991).

BACKGROUND

As part of the EPA's study of the future effects of acidic deposition on surface water chemistry, the DDRP, there arose a need for watershed-specific, average and WY84 runoff-depth estimates for ungaged sites. The USGS, in support of this project, produced an average annual runoff-depth map for the 1951-80 (long-term) period for the eastern United States (Krug, *et al.*, 1990), (Figure 3) (Plate 1), and a WY84 runoff depth map for the northeast United States (Graczyk, *et al.*, 1987), (Figure 4) (Plate 2). These maps were used to manually interpolate runoff estimates for the DDRP watersheds in the northeast United States (Church, *et al.*, 1989). The methods used in the creation of these runoff maps were based on the manual techniques developed by Gannett (1911), Langbein (1949), Knox and Nordenson (1961), Hely, *et al.* (1961), Schneider, *et al.* (1965), Busby (1966), and Gebert, *et al.* (1987). In this thesis this methodology will be referred to as the "manual procedure". In producing the long-term map Krug, *et al.* (1990) used long-term average runoff values from 1,232 gaging stations, the expert opinion of USGS hydrologists, topography, and past runoff maps. The WY84 map by Graczyk, *et al.* (1987) used 545 gaging stations and similar methodologies. A more detailed explanation of the methods used by Graczyk, *et al.* (1987) and Krug, *et al.* (1990) is presented in Chapter II.

The DDRP required a regional accuracy of site-specific values (*i.e.*, the region as a whole would require a mean percentage accuracy of X), as opposed to individual site accuracy (*i.e.*, each site would require a percentage accuracy of X) due to the regional outlook and scope of the project. The runoff values obtained from the

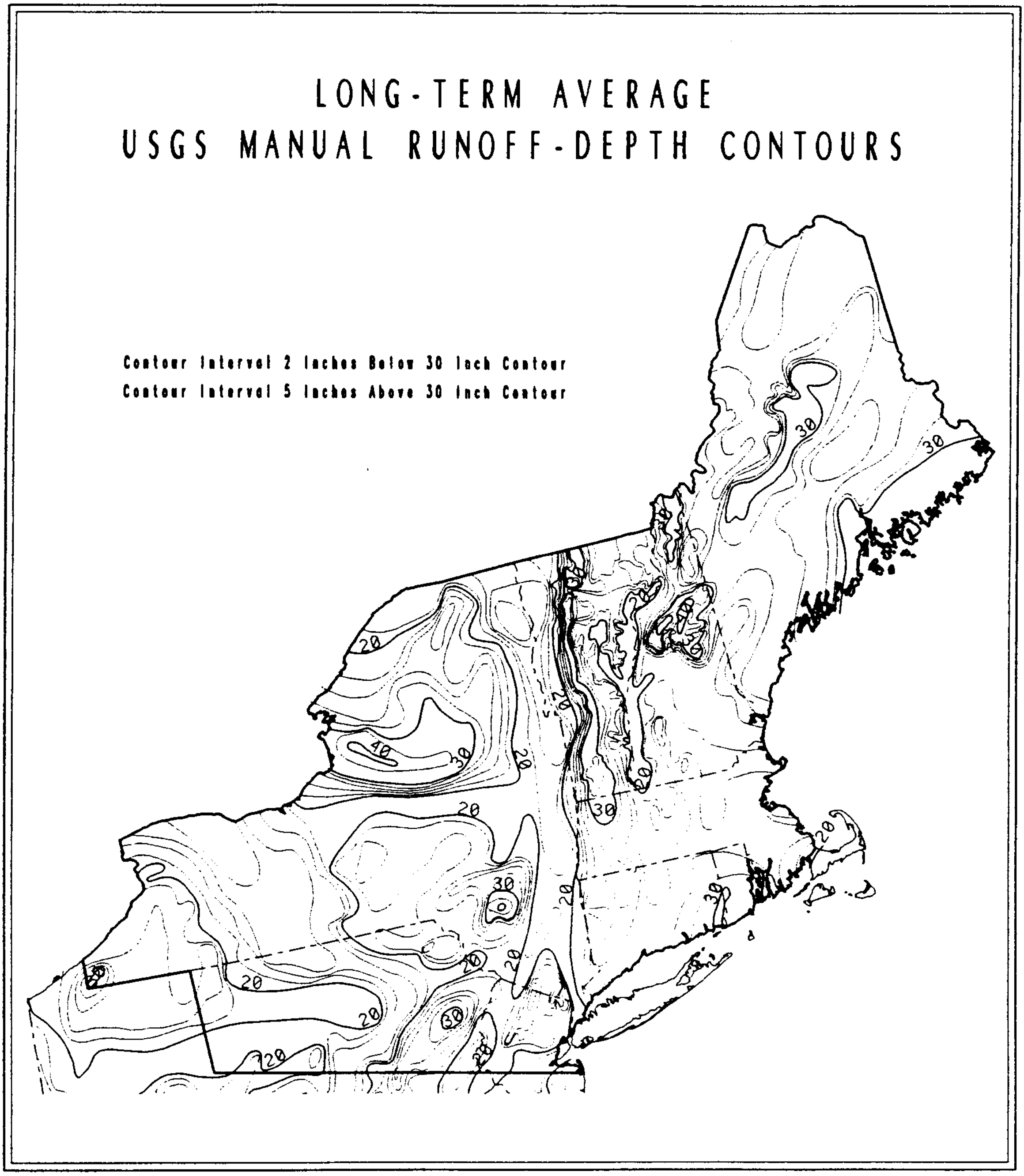


Figure 3. Long-Term (1951-80) Average Annual Runoff-Depth Contour Map. (Krug, *et al.*, 1990.)

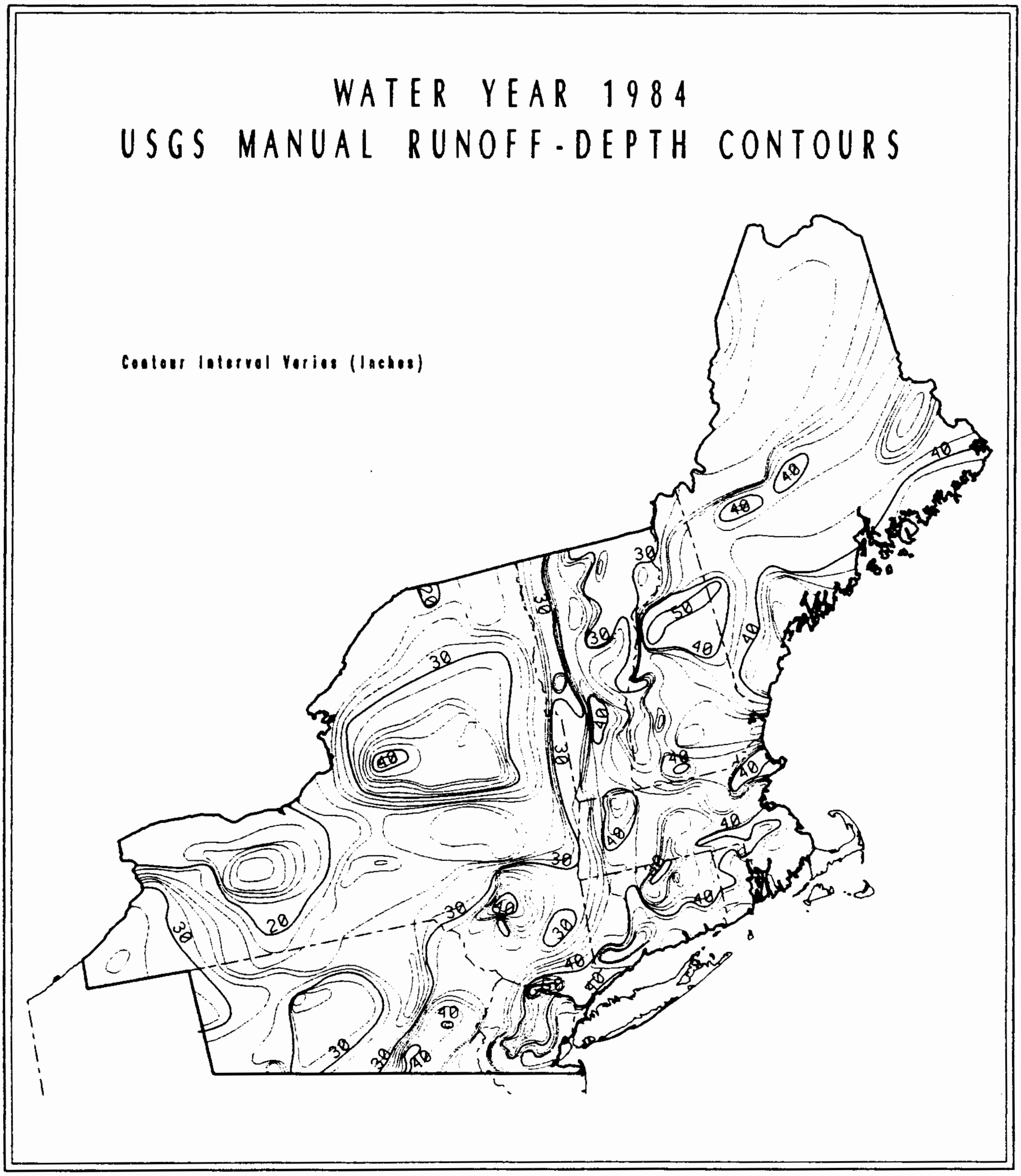


Figure 4. Water-Year 1984 Runoff-Depth Contour Map. (Graczyk, *et al.*, 1987.)

maps were used as one of the inputs to a watershed sulfur budget model and for sulfur retention estimates (Church, *et al.*, 1989). The errors associated with interpolating runoff values from a manual procedure-derived map for a regional project have been quantified (Table I) and found to be within acceptable limits (Rochelle, *et al.*, 1989). This research assumes that the mean error for the WY84 map produced by Graczyk, *et al.* (1987) using the manual procedure, is the same as that of the long-term map produced by Krug, *et al.* (1990).

TABLE I

INTERPOLATION ERROR DESCRIPTIVE STATISTICS
FOR WITHHELD SITES FROM A LONG-TERM RUNOFF MAP

Method	Population Mean	Standard Error of the Mean	Standard Deviation	Population Mean (Percent)	Standard Error of the Mean (Percent)	Standard Deviation (Percent)
Manual(1)	4.14*	0.92	8.91*	5.68	1.60	15.53
Manual(2)	1.54	0.88	8.53	0.90	1.47	14.21
GIS(1)	4.52	0.94	9.04	6.70	1.75	16.85

* cm.
(1) measured at basin outlet
(2) measured at basin centroid

Source: Rochelle, *et al.* (1989)

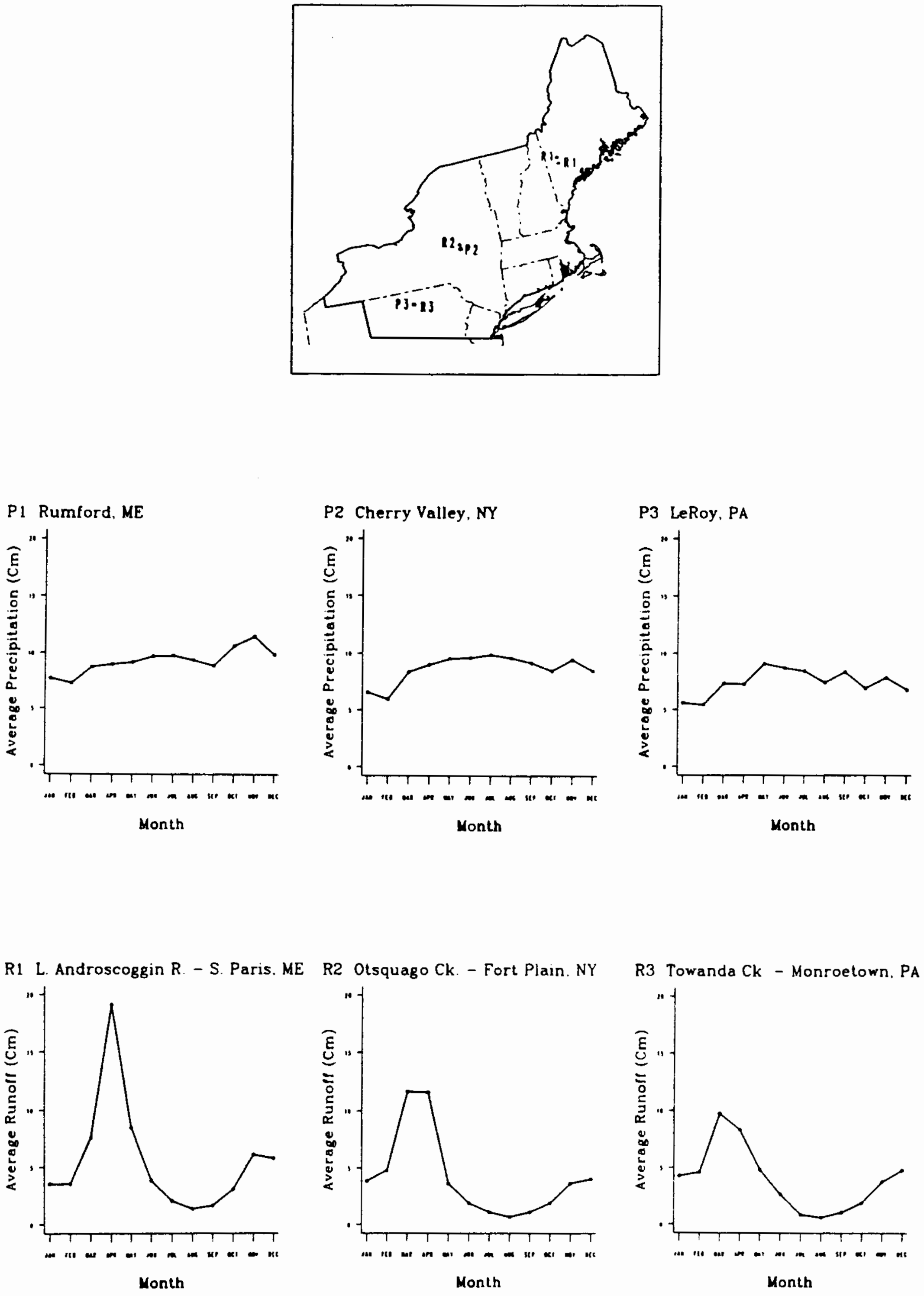
Hypothesis

This thesis hypothesis was that an automated procedure can produce a runoff map for the northeastern United States as accurate as that produced by the manual procedure. The method used in determining accuracy was an "uncertainty analysis". An uncertainty analysis is the withholding of data sites from a runoff map's creation for later use in a comparison of the actual withheld data to values obtained by interpolation to these sites from the map generated. The differences between these values, the interpolation error, was then used to quantify the map and the automated procedures accuracy by a comparison of the mean interpolation errors of the automated procedures to the mean interpolation error of the manual procedure.

PHYSICAL SETTING

The northeastern United States, here defined as the area covered by the WY84 runoff-depth map (Graczyk, *et al.*, 1987) (see Fig. 3), is a temperate region with moderate spatial variations in temperature and precipitation. Most of this variability is due to differences in elevation and distance from the coast. The region is cool and humid consisting of plains, plateaus, and mountains with elevations ranging from sea level along the Atlantic coast to 1,916 meters (6,288 ft) at Mt. Washington. The average annual temperature across the region ranges from 3 to 11 degrees Celsius. Most of the land in the region is forested, especially on the steeper slopes (USDA, 1981).

Average annual precipitation in the Northeast ranges from 70 to over 230 cm with the general trend being an increase in precipitation with elevation, although distance-from-coast and local rainshadow effects can be significant (Dingman, 1981). The amount of precipitation that falls as snow (based on a forty-year period of record) can range from 75 to over 380 cm annually (Miller, *et al.*, 1962). In general, precipitation is evenly distributed throughout the year (USDA, 1981) (Figure 5).



P1 Rumford, ME

P2 Cherry Valley, NY

P3 LeRoy, PA

R1 L. Androscoggin R. - S. Paris, ME

R2 Otsquago Ck. - Fort Plain, NY

R3 Towanda Ck - Monroetown, PA

Figure 5. Average Monthly Precipitation and Runoff for Selected Sites in the Northeast.

Thornthwaite, *et al.*, (1958) estimate that ET varies from 42 to 71 cm over the Northeast. Hidore (1966) gives a more generalized range of 51 to 89 cm for the east coast.

With regards to surface runoff, the highest flows occur in March or April due to a combination of snowmelt and rainfall with the lowest flows occurring in August or September (Miller, *et al.*, 1962) (Figure 5). Gebert, *et al.* (1987) characterized temporal variability of streams in the United States with a coefficient of variation calculated by dividing the standard deviation by the average flow at individual gage sites. Variations of annual values from the long-term mean runoff at gaged sites in the Northeast region were characterized as low or medium (*i.e.* the lower three quartiles of the coefficient of variation). A few scattered high variation sites are also present and can be found mainly in the southeast portion of the Northeast region.

Water-Year 1984

WY84 was a wetter than average year for the Northeast. A statistical summary comparing the long-term and WY84 periods is presented in Table II. At the 242 WY84 precipitation stations used in this research that have long-term data available, precipitation averaged 126% of the long-term average for WY84. There is a correlation of 0.88 between the two data sets, showing a linear relationship between the two data sets and little variation from the trend line. Of the 227 runoff gaging sites that have corresponding long-term data runoff on average was 141% of the normal for WY84 with a correlation of 0.75. These percentage-above-normal values are in general agreement with the National Water Summary for 1984 (USGS, 1985). The statistical distributions of the WY84 and long-term average regional precipitation data sets are not normal.

TABLE II

COMPARISON OF LONG-TERM TO WATER-YEAR 1984 GAGED VALUES* AT CORRESPONDING GAGED SITES

	Mean	Standard Deviation	Median	Minimum	Maximum
Precipitation (n=242)					
Long-Term	108.58	16.16	109.16	71.96	228.40
WY84	137.88	27.26	138.10	76.78	334.24
Runoff-Depth (n=227)					
Long-Term	62.04	12.03	61.72	30.48	106.68
WY84	86.97	18.60	87.55	33.76	146.86

*Data in centimeters of depth

DATA

The data used in this thesis are: 1) USGS long-term and water-year 1984 runoff-depth contour maps, 2) USGS long-term and WY84 stream-flow gaging information, 3) USGS gaging station watershed centroids, and 4) National Climatic Data Center (NCDC) long-term and WY84 climatological data. For the automated procedures 441 WY84 USGS centroid sites (Appendix A) were used with 228 centroids being obtained by matching USGS long-term centroid sites with water-year 1984 sites by the site identification number. The other 213 sites were obtained by manually mapping the gaging site basins on 1:500,000 and 1:250,000 USGS topographic maps and determining the centroids using a methodology similar to that used by the USGS. Watershed size ranged from 2 to 17,280 Km^2 and estimated centroid elevation from 12 to 898 meters. For precipitation, 358 long-term and 405 water-year 1984 NCDC precipitation sites were used in the analysis (Appendix B) whose elevations ranged from 0 to 1908 meters.

METHODOLOGIES

A literature review was conducted to determine the accuracies obtained, and the methodologies used to obtain these accuracies, from similar runoff-depth contour mapping work. All of the various methods base their accuracy measurements on comparisons of predicted runoff to actual runoff (*i.e.* predicted runoff - actual runoff = estimation error or accuracy). A wide range in accuracies was noted for the various methodologies. Values of estimated runoff are considered acceptable if they are within 15% of measured amounts (Shelton, 1985). Based on this review a regional accuracy similar to that obtained from the manual procedure (*i.e.* a mean error of 0.9% with a standard deviation of 14.2% (Rochelle, *et al.*, 1989)) will be considered acceptable for the automated procedures tested in this thesis.

Eight various automated procedures were developed and tested to find an acceptable method of producing a runoff-depth contour map for WY84. A statistical and visual comparison to the manual map for WY84 was conducted. Five of the procedures were chosen for further study with an uncertainty analysis.

For the uncertainty analysis a contour map was produced for each of the five procedures with a randomly chosen subset of the runoff-depth gaged sites withheld from each process. The withheld sites were chosen with a spatial clustering procedure. This procedure selected a spatially unbiased random sample of 50 of the WY84 runoff sites to be withheld from each of the automated methods (Stevens, 1991). Values were interpolated to the withheld sites from the contour maps produced. The interpolated values minus the actual values were then calculated with the mean difference, *i.e.* mean interpolation error, defining the accuracy of the maps produced (*e.g.* Rochelle, *et al.*, 1989).

ORGANIZATION OF THESIS

This thesis is divided into five chapters. The first has given a general overview of the purpose, data, methods, and the region of study. The second chapter gives a brief history of runoff-depth contour maps and reviews the methodologies currently in use. The third chapter discusses the eight automated methods originally considered for producing runoff-depth maps and the selection of the five automated procedures used in the uncertainty analysis. The fourth presents and discusses the results of the uncertainty analysis of these five procedures. The fifth chapter summarizes the results, states the conclusions of the thesis, and suggests some future areas of research.

SUMMARY

Mapping runoff-depth is a difficult, expensive and time consuming task. Research was conducted in conjunction with the DDRP (Direct Delayed Response Project) to find an automated procedure that will provide runoff-depth contour maps with a regional accuracy equivalent to that of maps produced by the manual procedure, but with a lower cost in both time and money. Eight procedures were developed to meet these requirements and five of them were selected for further examination with an uncertainty analysis.

This thesis hypothesized that the manual and five automated procedures examined are equivalent. It tested this hypothesis by comparing the results of an uncertainty analysis of the long-term manual procedure derived runoff-depth contour map (Rochelle, *et al.*, 1989) to the results from the uncertainty analysis of the five maps produced with the automated procedures. The goal of a mean percentage error approximating 0.9% was set for the automated procedures.

CHAPTER II

REVIEW OF THE LITERATURE

INTRODUCTION

Runoff-depth contour maps show the amount of surface water flowing from a given area expressed as equivalent water depth. Runoff-depth can be visualized as being the residual of precipitation after the demands of evapotranspiration have been met (assuming that changes in groundwater storage are zero) (Langbein, 1949). The time interval that is mapped varies, but is usually annual (water-year) or long-term average (30 years).

The uses of runoff-depth contour maps include the evaluation of water resources and for scientific and educational purposes (McKay, 1976). Runoff-depth maps can also be useful for estimating the discharge at streams which are not gaged. A research project which could not gage the streams of interest due to the project's size, budget, and time constraints found these maps to be useful (Church, *et al.*, 1989). Estimating average runoff from these maps can be helpful in determining the feasibility of projects such as hydroelectric dams before more detailed studies are done (Solomon, *et al.*, 1968). Users of these maps must keep in mind, however, that local conditions can influence greatly the spatial pattern of runoff, and thus what is shown on a generalized regional map may not reflect specific local conditions (Krug, *et al.*, 1990). Runoff can be even more variable over time than precipitation in some areas; so using an annual-mean runoff-depth map to predict a given year's runoff can produce large errors in the estimate (Leopold, *et al.*, 1964).

HISTORY

In the United States the majority of runoff-depth contour maps are produced by the U.S. Geological Survey (USGS) using stream gage data. Stream gaging started in the United States in about 1890 and in 1892 a runoff-depth map, likely the first in the United States, was produced by F.H. Newell (Langbein, *et al.*, 1949). By 1910 there were 1000 gaging stations in the United States (Thornthwaite, *et al.*, 1958) and in 1911 Gannett produced a map which supplemented gaging data with estimates of runoff in ungaged areas. Estimated "water loss", evapotranspiration (ET), was subtracted from precipitation values in the ungaged areas (Gannett, 1911). In 1934, when there were 3000 gaging stations (Thornthwaite, *et al.*, 1958), the water planning committee of the National Resources Board published a map using similar techniques. A technique using an empirical formula, utilizing temperature and precipitation data, was developed by Thornthwaite and published in 1945 (Langbein, *et al.*, 1949). In 1949, when there were 6000 stations (Thornthwaite, *et al.*, 1958), Langbein produced a map using actual and estimated runoff, along with the expert opinion of hydrologists (*i.e.* the manual method). This has been the predominant method of mapping runoff-depth in the U.S. ever since.

DESCRIPTION OF CURRENT METHODS OF CREATING RUNOFF-DEPTH CONTOUR MAPS

One broad group of methods currently in use are the water-balance methods. This methodology assumes that if all except one element of the water-balance (Formula 1) are known the missing value can be calculated.

Formula 1.

$R = P - ET (+-) S$

R = Runoff, P= Precipitation, ET = Evapotranspiration, S = Storage

This method is more practical for long periods of time, such as a year or more (*e.g.* annual mean), where changes in storage can be assumed to be negligible (Kitteredge, 1938, Storr, 1972, Dunne and Leopold, 1978, Lee, 1980, Domokos and Sass, 1990). The methodology most often used is to calculate ET by empirical formulae such as those of Thornthwaite, Penman, or Blaney-Criddle, using data such as temperature and wind speed, collected at or near a precipitation station (Dunne and Leopold, 1978) and then subtracting ET from precipitation to get estimated runoff. Thornthwaite, *et al.*, (1958) stated that their method of estimating runoff, via the water-balance, is superior to direct gaging because the groundwater that seeps past gaging sites, which may be in significant amounts, goes unmeasured. Others have questioned the relative accuracies of the various methods of estimating ET, thus casting doubt on which aspect of the water balance (*i.e.* estimated ET or measured runoff) brings with it a larger error (Van Wijk and DeVries, 1954, Dunne and Leopold, 1978, Lee, 1980). The accuracy of the water balance method has not been quantified from maps based on this method, although estimates for individual basins have been calculated with the results "approximating" or in "good agreement" with actual measured values (Thornthwaite, *et al.*, 1958, Mather, 1981).

Regression techniques are another major method of producing runoff-depth contour maps. The technique relates through a formula the dependent variable, runoff or ET, with independent variable(s) such as elevation, precipitation, and temperature, at locations where all these variables are known or can be reasonably estimated. By statistical techniques or intuitional/deductive reasoning a researcher chooses which independent variables best predict the dependent variable at the known sites. The formula generated is then used at other sites where the independent variables are known. A detailed description of the techniques, mathematics, and theory involved can be found in Holder (1985). An example of this technique is the work of Liebscher (1972) who used mean annual precipitation, temperature and the ratio of summer-to-winter precipitation to map average runoff-depth in West Germany (Figure 6). His runoff-depth map was created by hand interpolation from regression-derived estimated runoff and actual runoff values. The map's main purpose is to prepare large area water balances. The strengths of the regression method are that it is reproducible and that the confidence one can place on the regression estimate is quantifiable. Weaknesses include the often subjective

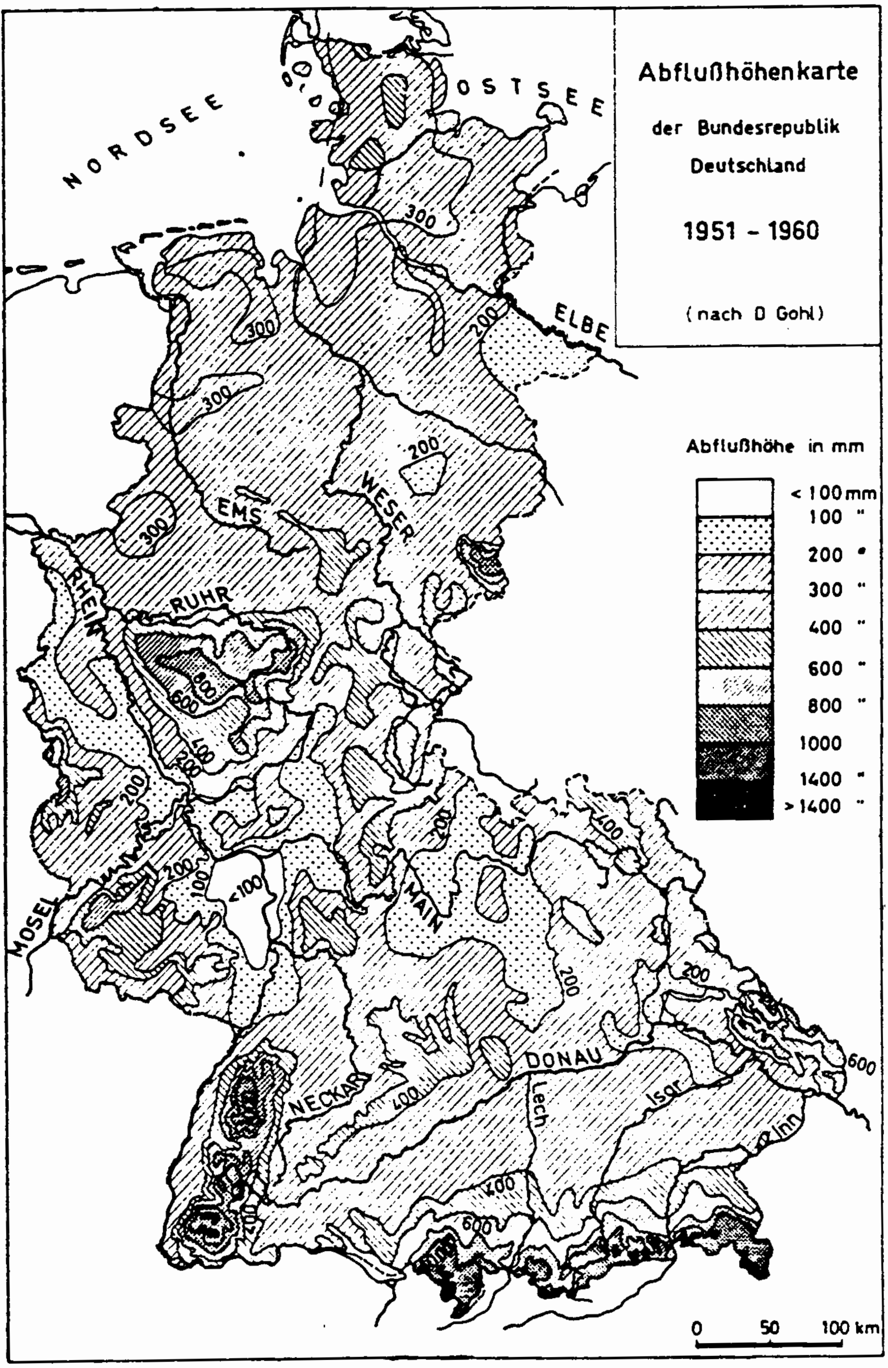


Figure 6. Regression Method Map of Mean Annual Runoff-Depth for West Germany. (Source: Liebscher, 1972.)

decision as to which independent variables to include in the regression formula. The accuracy of maps produced by this method have not been quantified.

Another broad group of methods can be called the grid square technique. In this method the area of study is divided into a uniform grid, suitable for use in a raster based data system. Various physiographic attributes such as elevation and distance from the coast are calculated for each grid. From grid squares that contain meteorological or gaged sites precipitation, runoff, and ET (from empirical formulae) are calculated or measured and correlated to the physiographic data by regression formulae. Values are then extrapolated to the other grid cell sites and, after minor refinements based on withheld data, a map is produced (Solomon, *et al.*, 1968). A variant method is to use estimated precipitation and ET in a water balance formula developed by Penman that employs a soil moisture component to estimate runoff (Foyster, 1975). The grid square method's main strength is the ease with which estimated discharge of a stream can be calculated by using the estimated runoff for the grid cells in the watershed and the grid size. The weakness of this technique is the generalizations that will occur due to the use of a uniform grid over an amorphous drainage pattern. Calculating from Foyster's (1975) estimated values for five sites in southeast England from one application of this technique, estimated discharge varied from -7 to +16% of actual measured discharge with a mean error of 5.43% and a standard deviation of 9.50%.

The last method to be considered is the creation of runoff-depth contour maps by manual interpolation. The basic hypothesis of this method is that an expert hydrologist, using gaged data and taking into account meteorological and physiological factors, can produce a reasonably accurate runoff-depth map. This method has been extensively used by the USGS (Gannett, 1911, Langbein, *et al.*, 1949, Knox and Nordenson, 1957, Schneider, *et al.*, 1965, Busby, 1966, Gebert, *et al.*, 1987, Graczyk, *et al.*, 1987, Krug, *et al.*, 1990). Applications include contributing to scientific knowledge and the estimation of runoff at ungaged streams (Langbein, *et al.*, 1949, Krug, *et al.*, 1990). An advantage of this method is that hydrologists are not constrained by a fixed formula or methodology and thus can take into account local variations or anomalies in the physical environment when creating the contours (UNESCO/WMO, 1977). Conversely, the human element can be considered the weakness of this method since errors in judgment or oversight can occur. Errors of estimates from a long-term map of the eastern U.S. created with this method (Figure 7) were quantified by Rochelle, *et al.*, (1989). The mean error of estimated as compared to actual runoff values was 0.9% (Rochelle, *et al.*, 1989). Domokos and Sass (1990) gave estimated runoff derived from their manually produced runoff map for 24 large sub-basins in the Danube basin (although it is unclear whether these sites were withheld from the map's creation). From their results a mean error of 0.14% and a standard deviation of 2.69% were calculated with errors varying from -4.14 to +4.79% of recorded values (Domokos and Sass, 1990).

Figure 7. Manual Method Map of the Mean Annual Runoff-Depth in the Eastern United States. (Source: Church, *et al.*, 1989.)

DISCUSSION OF FINDINGS

Examples of the Use of Runoff-Depth Contour Maps

An example of the use of runoff-depth maps is the work of Solomon, *et al.*, (1968) who produced a runoff-depth map of Newfoundland and Labrador to help assess potential hydropower in the region. The project was conducted by the Atlantic Development Board, Government of Canada. Although no specifics of alternative methods considered were discussed in their paper, the authors state the reasons for choosing an automated procedure, the grid square technique, as being the need for moderate accuracy over the large 140,000 square mile area as well as the large amounts of data that needed to be stored, processed and retrieved quickly for the project (Solomon, *et al.*, 1968).

Domokos and Sass (1990) recently reported on a project using runoff-depth contour maps for resource appraisal in the Danube basin. Under international agreement the countries in the basin, using predetermined uniform methodologies, created runoff-depth contour maps using the manual method (Figure 8). The authors do not state why this methodology was chosen but they consider the results to be "acceptable, or even satisfactory". They feel that their results are applicable to future resource planning in the Danube Basin (Domokos and Sass, 1990).

The U.S. Environmental Protection Agency (EPA), in cooperation with other federal agencies, recently completed a study of the potential future effects of sulfur deposition in the eastern U.S., the Direct/Delayed Response Project (DDRP). Estimates of runoff were needed for input-output ion budget models, using long-

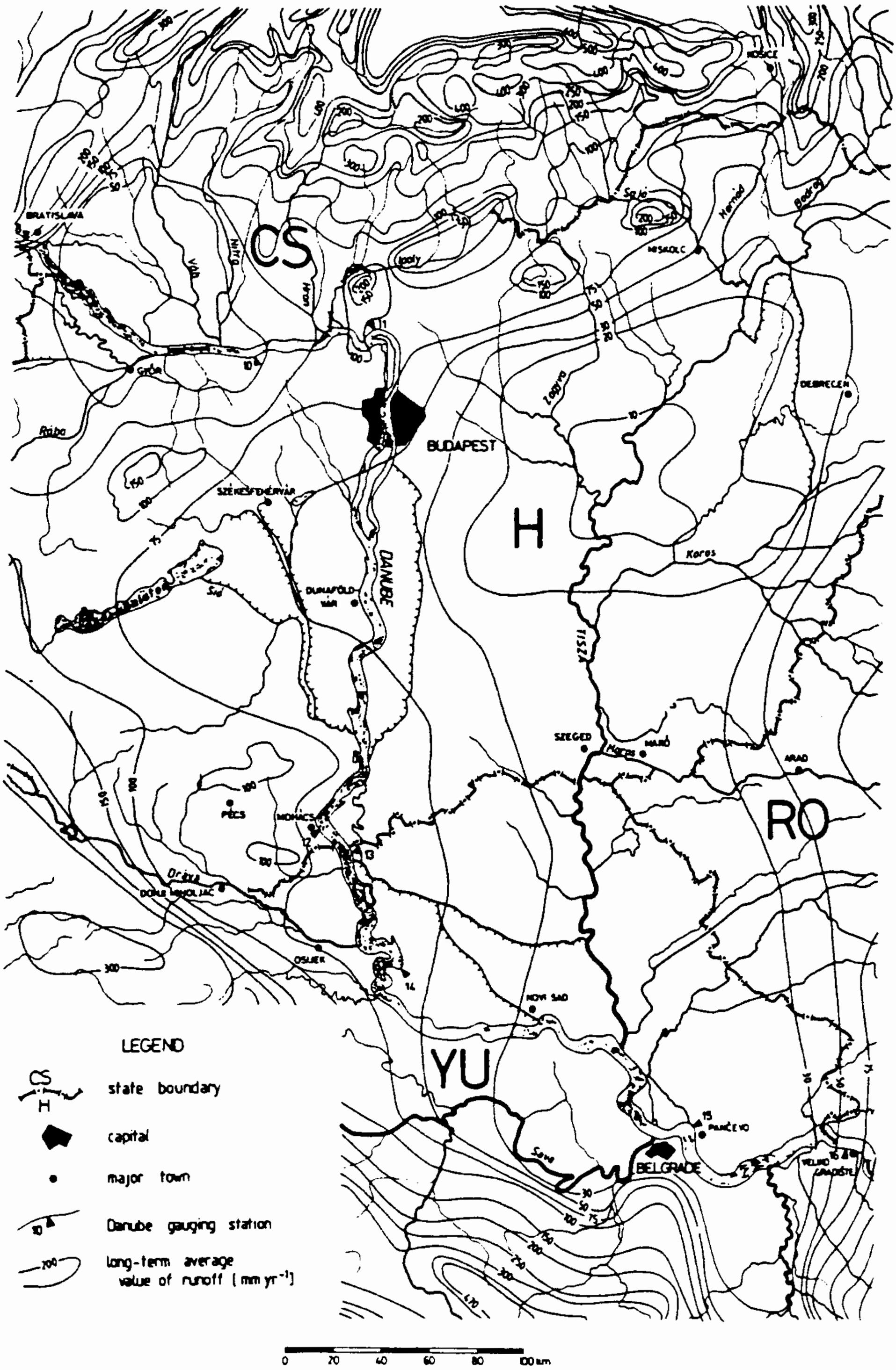


Figure 8. Manual Method Map of Mean Annual Runoff-Depth in the Danube Basin. (Source: Domokos and Sass, 1990.)

term average values (Krug, *et al.*, 1990), and for sulfur retention estimates for which "typical-year" data were used (*i.e.* for the northeast United States, WY84) (Graczyk, *et al.*, 1987). The DDRP was faced with three choices for obtaining runoff values: 1) gage the approximately 1800 sites, 2) use an empirical interpolation approach, such as kriging, or 3) interpolate estimated runoff from runoff-depth contour maps produced with existing runoff data and the expert opinion of USGS hydrologists. Budget and time constraints made the first option impractical, while the large variability in topography and other variables that influence runoff across the region was felt to limit the accuracy of the second method. Runoff-depth maps produced by the third option at an appropriate resolution were not available at the time the project started. The USGS was employed to create the necessary maps by the manual method (Graczyk, *et al.*, 1987, Church, *et al.*, 1989, Rochelle, *et al.*, 1989, Krug, *et al.*, 1990). Runoff estimates were interpolated from the maps to the center (*i.e.* centroid) of each DDRP study watershed. An analysis of the errors associated with the estimates was conducted using an uncertainty analysis and the errors were found to be within acceptable limits (Church, *et al.*, 1989, Rochelle, *et al.*, 1989). The director of the DDRP has noted that if a more precise automated empirical method had been available the project would have utilized it and thereby reduced the considerable expense (*e.g.* the water-year 1984 map for the northeast United States cost approximately $25,000) and time spent in having the maps produced manually (Church, 1991).

Choosing an Appropriate Method of Mapping Runoff-Depth

With the variety of methods of mapping runoff-depth that are available, the question facing researchers is which method of producing a map is best for the situation at hand. There are five interrelated factors that affect the choice of an appropriate method for a given project: scale, desired accuracy, available data, available funding, and available time. The scale of the project under consideration is critical since a large discrepancy between the scale of a project and that at which the map is created can result in large errors or needless accuracy in the estimate of runoff. For example, if one is going to build a small agricultural storage dam on a ten square kilometer watershed one does not use a map of average runoff-depth for the United States. Conversely, if one was examining the general runoff patterns in the Columbia River basin, one would not need to estimate runoff for every square kilometer to get a good idea of the spatial pattern of runoff. Scale becomes less critical in areas of gentle relief were the pattern of runoff tends to be more homogenous. Generalization on smaller scale maps also affect the accuracy of the estimate obtained (UNESCO/WMO, 1977). This brings up the second factor, desired accuracy, which again depends upon the project at hand, as well as available data. Accuracy depends on the spatial density of data as well as variations in topography, geology, *etc.* (Krug, *et al.*, 1990). Thirdly, the available data can limit the choice of methods used. If only runoff data are available, then a manual method can be the best choice. As climatological and physiographic data become available, the other methodologies become practical. Fourthly, the available funds can influence the method chosen. If the appropriate geographic and statistical software are available, an automated procedure (*i.e.* regression, grid square) is usually the most cost effective. If funds are limited and trained personnel are available, the manual method can be an acceptable short-term, cost-effective method. Lastly, the available time for completion of a project can be critical since manual techniques are often more time consuming than automated procedures.

The five factors are often interrelated with each aspect needing to be weighed carefully against the others, thus complicating the decision process that a person must face. If a project's scale is large (*e.g.* states to regions) and gaged runoff data, along with physiographic and climatic data are available, then automated procedures might be suitable. In smaller areas, the mapper will have to depend more on expert opinion or interpolative techniques, such as the regression or the grid square method. As the size of the area under consideration shrinks further one will have to extrapolate specific runoff and other information from relatively large distances and one could be forced to rely on manual or simple regression techniques. At all scales it is important that the data be as homogenous and temporally equivalent as possible (UNESCO/WMO, 1977).

Current Status and Future Prospects of Runoff-Depth Contour Maps

The current status of runoff-depth mapping in the United States is one in which newer, more automated procedures have largely gone unused. Although the manual method is adequate, it is likely that accuracy and efficiency could be improved by using partially or fully automated procedures (UNESCO/WMO, 1977). Some preliminary work has been started to merge the advantages of the manual method (*i.e.* expert opinion), with the advantages of automated procedures (*i.e.* speed and reproducibility) (Church, 1991); but a full scale research program has not been started. The use of artificial intelligence (expert systems) is an area of great promise for creating runoff-depth maps. Development of a system that uses the thought processes and approaches used in the manual method should be relatively straightforward (Church, 1991).

Summary

Runoff-depth maps aide the researcher and water manager in taking the first step in managing a resource, *i.e.* appraisal. These maps can be useful for estimating runoff at ungaged sites, in hydroelectric planning, and in providing general knowledge of runoff patterns. Researchers should keep in mind the relative scale of a project versus the map to be used, the accuracy needed for the task at hand, as well as the data used in creating the map. Due to the generalizations inherent in such maps, the map user needs to be cognizant of possible effects that local conditions might have on runoff-depth estimates at the site(s) of interest if these maps are to be used effectively. Research should be encouraged in the development of artificial intelligence methodologies for producing runoff-depth contour maps. These methodologies offer the best hope of improving the accuracy and availability of runoff-depth contour maps (Church, 1991).

CHAPTER III

AUTOMATED PROCEDURES USED IN MAPPING RUNOFF-DEPTH

INTRODUCTION

In conjunction with research for the Environmental Protection Agency's (EPA) Direct/Delayed Response Project (DDRP) a study was conducted to find simple automated procedure(s) for producing annual (water-year) runoff-depth contour maps. The goal was for the procedure(s) to have a regional accuracy similar to that of the manual procedure maps produced by the U.S. Geological Survey (USGS) as quantified by Rochelle, *et al.* (1989). From several general methodologies eight specific procedures were examined to find a method that met these criteria.

Part of the underlying strategy of the methods tested is to densify the network of known runoff-depth value sites by using climatological data from National Climatic Data Center (NCDC) precipitation stations in the region of study, (*i.e.* the northeast United States) to estimate runoff at these stations.

The WY84 map produced by Graczyk, *et al.* (1987) was chosen as the runoff-depth map to be produced by the automated procedures to be examined. This map was chosen because: 1) it was produced by the same methodology as the long-term map produced by Krug, *et al.* (1990) whose accuracy was quantified by Rochelle, *et al.* (1989), 2) the WY84 USGS runoff gaging site data were readily available, 3) the precipitation data for WY84 were readily available, and 4) WY84 was a wetter than average year following a normal year in the northeast United States (USGS, 1984, 1985), thus minimizing the effects of ground and surface water storage changes on the analysis. Eight different procedures were compared with statistical and visual techniques to the manual method. Based on this comparison procedures for further testing with an uncertainty analysis were chosen.

Rationale for Automation

Automated procedures have many advantages: lower cost and time as compared to manual procedures, ease of data handling, and reproducibility. Automated methods have been found to be an effective means of mapping runoff (*e.g.* Foyster, 1975). Automated procedures have disadvantages though: being unable to handle unforeseen or local influences on the phenomena being mapped, difficulty in accurately mapping non-homogeneous data or source networks, and handling the influences of mountainous terrain (McKay and Thomas, 1971, UNESCO/WMO, 1977, Dingman, *et al.*, 1988). In this thesis these disadvantages were felt to be largely overcome by the use of estimated runoff at precipitation stations densifying the known runoff sites used for interpolation. This densification, along with the uniformity of data used and the regional scale of accuracy desired, was felt to make the automated procedures comparable to the manual methods.

Simplifications at the Regional Scale

One of the assumptions of this research is that due to the broad regional scale being utilized, a relatively unsophisticated methodology will be appropriate. As noted by Palmer and Havens (1958), "Although ease of application is not a suitable criterion of adequacy, it is often a primary consideration of use" (p. 123). As part of the philosophy of simplification the use of simple water-balance, rainfall-to-precipitation ratio (R/P), and regression techniques were explored. Contours were generated by linear interpolation also for the sake of simplicity.

At the scale of this study the area of the watershed compared to the study area is small and thus it was felt appropriate to treat the areal runoff values as points (Foyster, 1975). The runoff sites are placed in the center of their appropriate drainage basin, as opposed to the actual gage site, in accordance with standard USGS runoff-depth mapping policy (Graczyk, *et al.*, 1987, Rochelle, *et al.*, 1989, Krug, *et al.*, 1990).

At the regional scale the use of a water balance approach was felt to be suitable (Foyster, 1975). The longer time periods considered (*i.e.* water-year and long-term average) preclude the need to consider change in storage although local conditions, such as geology, may cause these assumptions to be invalid in some areas (Kitteredge, 1938, Storr, 1972, Dunne and Leopold, 1978, Lee, 1980). When accurate measurements of precipitation (P) and runoff (R) are available the calculation of evapotranspiration (ET) is straightforward (ET = P - R), although the concept of "accurate measurement" can be a major problem (Munson, 1966). Even if the assumption of zero change in storage is false the possible errors in the measurement and estimation of runoff and precipitation values could override this usually small amount.

Another simplifying concept in the use of a regional scale is that averages or integrals of factors affecting runoff process at a more local scale can be generalized (Klemes, 1983). Things that might appear anti-intuitive at the large scale, *e.g.* the storage component of the water balance being ignored, can be assumed to hold true at the regional scale over longer time periods (McKay and Thomas, 1971).

Underlying Assumptions with Principal Data Used

For this research long-term runoff-depth values were obtained by interpolation from the long-term runoff-depth map (Krug, *et al.*, 1990). These values were used because of the quantifiable nature (Rochelle, *et al.*, 1989) of the interpolated values at ungaged sites and because they are more accurate than interpolations from gaged sites alone. It has been found that estimates of runoff-depth obtained from the long-term runoff-depth map are not regionally or spatially biased or biased due to the local density of sites used in the map's creation (Rochelle, *et al.*, 1989). There also is no bias in estimates due to basin size from the long-term runoff map (Rochelle, *et al.* 1988). The gaged and interpolated values of runoff-depth used in this research do not take into account the errors in stream gaging which have been estimated to range from 0-5% (Winter, 1981) to 10-15% (Mather, 1981).

An underlying assumption of the long-term precipitation and runoff data used in this research is that they define a climatic normal and that, through various methods, a prediction for a given year's runoff, outside of the time frame used in determining long-term average precipitation and runoff, can be made. Work by Drozdov, *et al.* (1965) and Court (1967) has found that the 30-year period used to define climatic normals for precipitation is without scientific foundation. Court (1967) found that for precipitation estimates the longer the year to be predicted is from the base period (*i.e.* the period defining climatic normal) the shorter the climatic normal time period needs to be. It is unknown whether this also applies for runoff. The 30-year base period was used in this research because of the ease of data acquisition, its widely held acceptance, and because it was the time period used in the generation of the long-term runoff map, not due to any inherent superiority to this time length.

Definitions of Elements of the Water-Balance

Precipitation will be defined as the water depth collected and recorded at standard rain gauges. An attempt was made to locate an expertly drawn long-term precipitation contour map at the same resolution and scale as the long-term runoff map, but none were available. This limited the research to using gaged precipitation data. Estimates of errors in precipitation measurement vary (Table III) and no attempt was made to correct for these errors, which overall have a negative bias (Rasmusson, 1968), in this research. The reasons for these errors include operator error, wind (Neff, 1977, DeAngelis, *et al.*, 1984), snow (Dingman, *et al.*, 1988), and occult precipitation (*e.g.* fog drip, rime) (Dingman, 1981). Dingman (1981) notes that occult precipitation can be significant in higher forested watersheds. Work by Yoxall (1980) and others has shown the importance of having an adequately dense precipitation station network to show the spatial pattern of precipitation and to accurately estimate this element of the water balance. No studies describing the required density of precipitation sites for a study at the regional scale are available in the literature, although a study by Dingman, *et al.* (1988) in West Virginia had an average error of 7.5% for estimating precipitation in a mountainous terrain were station density was 900 km^2/gage. Precipitation site density for the study region in this research was 929 km^2/gage for the long-term sites and 821 km^2/gage for the WY84 sites.

TABLE III

ESTIMATED ERRORS IN PRECIPITATION MEASUREMENT FROM STANDARD RAIN GAUGES

% Error	Time Frame	Study	Source
5-50	Annual	Struzer, *et al.* (1965)	Rasmusson (1968)
5-15	4-5 Years	Neff	Neff (1977)
0-30	Annual	Rodda (1985)	Dingman, *et al.* (1988)

Runoff will be defined as the amount of surface-water measured at a gaging site by the USGS. Runoff-depth is this measured volume spread over the upstream watershed area (volume of runoff/area).

Evapotranspiration is defined here as the remainder of precipitation once runoff-depth is subtracted. This is assumed to be equivalent to the amount of water evaporated and transpired for a given location. This definition would not be valid if variations in deep or surface storage were significant; but due to the longer time periods and large areas involved in this research it is felt that these variations are negligible at best. The longer time periods considered will also tend to reduce the cumulative errors caused by inaccuracies in the measurement of runoff and precipitation (UNESCO/WMO, 1977).

AUTOMATED MAPPING METHODOLOGIES CONSIDERED

To create a runoff-depth contour map as accurate as that produced by the USGS manual procedure for WY84 with a simple automated procedure several general methodologies were considered: 1) a linear interpolation method employing known gaged runoff data only; 2) a water-balance approach in which ET, determined from long-term data, is assumed to be constant; 3) a method which assumes that R/P, determined from long-term data, remains constant over time; 4) a regional mean approach to 2) and 3); 5) a regression formula approach which uses long-term data to create a formula to predict runoff or ET in WY84; and 6) a regional mean approach utilizing R/P based on WY84 data only. From these general methodologies eight specific procedures were formulated. For all of the procedures to be described here an ARC/INFO[*] GIS was utilized on a mainframe platform. Interpolations were based on Triangular Irregular Networks (TIN's) representing the given surface by a series of points of known values interconnected by triangles (ESRI, 1986). All interpolations and contours were visually checked against actual and estimated values plotted on the same map.

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[*] Mention of brand names or commercial products does not constitute endorsement or recommendation for use by the author, Portland State University, or the U.S. Environmental Protection Agency.

The first methodology is a map created from the linear interpolation of gaged WY84 runoff-depth data. This methodology was utilized to test whether any benefit was derived from the use of the above methodologies to follow when compared to this simple procedure. The steps involved in this procedure are: 1) Create a TIN for the gaged WY84 runoff values; and 2) produce a contour map, by linear interpolation, for WY84 runoff using the TIN created in 1). This method is diagramed in Figure 9 and will be referred to as the GAGE84 procedure.

The second methodology assumes that ET is constant over time. ET has been found to be conservative in space and time (Leopold, *et al.*, 1964, Likens, *et al.*, 1977, Lee, 1980, Saxton, 1981). This simplification (assuming ET is constant over time) was felt to be reasonable considering the other possible errors in the water-balance calculation (*e.g.* measurement errors). The steps involved in this procedure are: 1) create a TIN for long-term runoff from the long-term manual map; 2) interpolate long-term runoff to the long-term precipitation stations using the TIN produced in 1); 3) calculate, from the interpolated runoff and measured precipitation, the long-term ET value for each precipitation station; 4) create a TIN from the long-term ET values calculated in 3); 5) interpolate long-term ET to the WY84 stations using the TIN created in 4); 6) calculate estimated runoff using precipitation and ET values at each precipitation station (estimated R = P - ET); 7) create a TIN using both the estimated runoff at the precipitation stations and the gaged runoff; 8) generate a contour map, by linear interpolation, for WY84 runoff using the TIN created in 7). This methodology will be referred to as the LTET procedure (Figure 10).

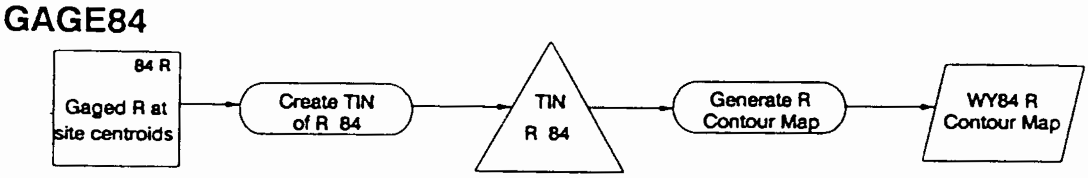


Figure 9. Steps in the Production of a Runoff-Depth Contour Map Using the GAGE84 Procedure.

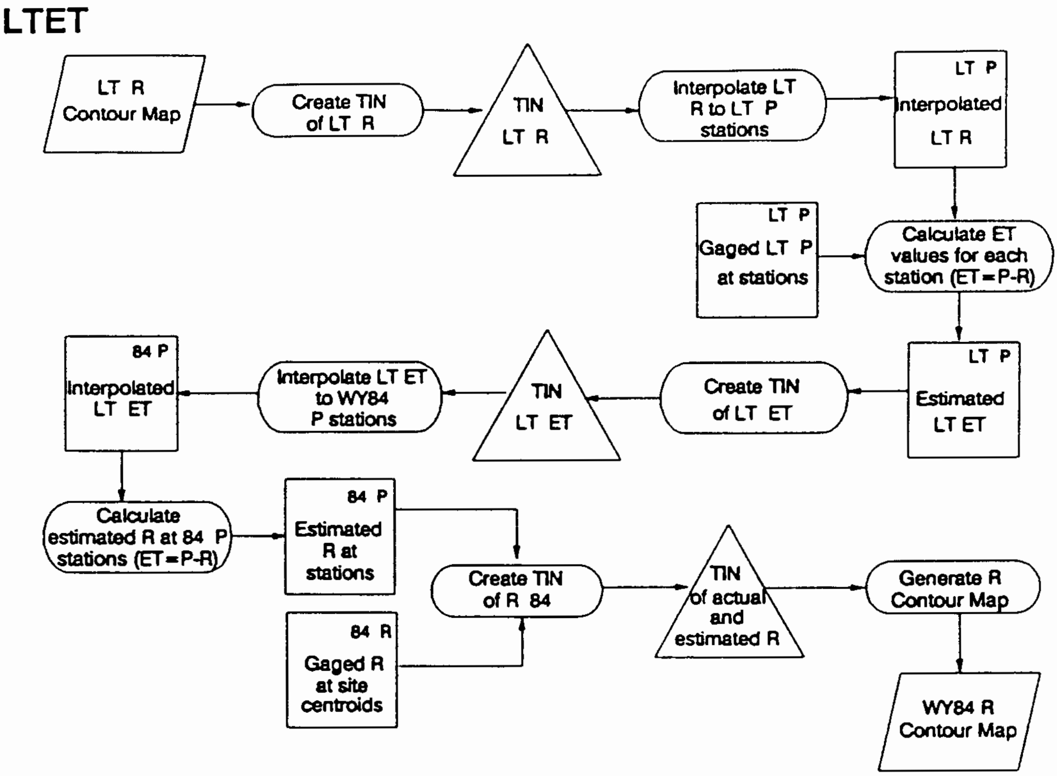


Figure 10. Steps in the production of a Runoff-Depth Contour Map using the LTET Procedure.

The third methodology assumes that R/P remains constant over time. Although the literature does not support this hypothesis either for individual watersheds having a constant R/P or as a predictor for other ungaged streams (Rafter, 1903, Hidore, 1966), it was felt that this approach met the criteria of simplicity, and at the regional scale it was assumed that the errors introduced would be tolerable. The steps involved in this procedure are: 1) create a TIN for long-term runoff from the long-term manual map; 2) interpolate long-term runoff to the long-term precipitation stations using the TIN produced in 1); 3) calculate, from the interpolated runoff and measured precipitation, the long-term R/P value for each station; 4) create a TIN from the long-term R/P values calculated in 3); 5) interpolate long-term R/P to the WY84 precipitation stations using the TIN created in 4); 6) calculate estimated runoff using precipitation and R/P values at each precipitation station (estimated R - P(R/P)); 7) create a TIN using both the estimated runoff at precipitation stations and the gaged runoff; 8) generate a contour map, by linear interpolation, for WY84 runoff using the TIN created in 7). This methodology will be referred to as the LTRP procedure (Figure 11).

The fourth methodology uses the MLRA regional mean values of methods two and three to predict WY84 runoff. Due to the inherent noise in the results from individual sites, caused by measurement errors or local conditions as compared to the region as a whole, it was felt that using a regional mean of the ET and R/P values might give a more generalized and regionally correct result. The use of regional means as hydrologic predictors is supported by the work of Sopper and Lull

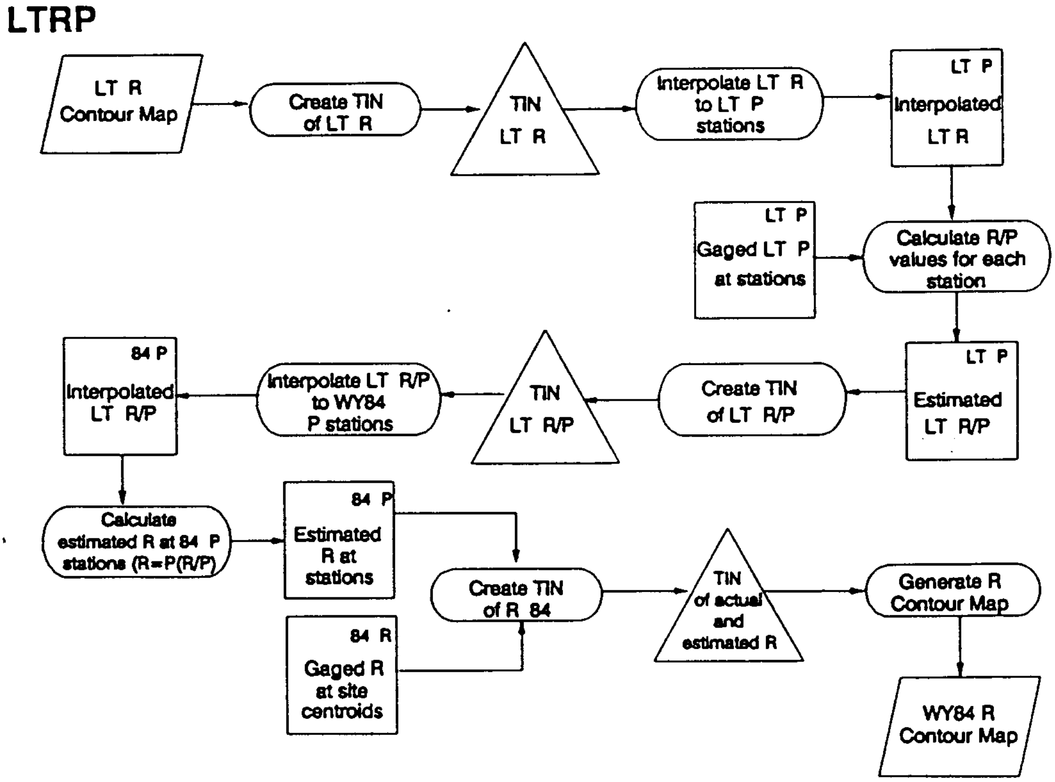


Figure 11. Steps in the Production of a Runoff-Depth Contour Map Using the LTRP Procedure.

(1965,1970) who found that experimental watershed runoff was in relatively close agreement to regional averages and Moss and Dawdy (1973) who found that regional values are valid for interpolating to ungaged sites. In producing the long-term R/P and ET values two methods were used. One was interpolating long-term runoff from the manual USGS map to long-term precipitation stations; the other interpolates long-term precipitation to the long-term runoff centroids. Between the two methods for determining R/P there was a statistically significant difference between the means of the two data sets ($Z = 4.90$ $P < 0.001$ (The P statistic gives the smallest level of significance that would have allowed the rejection of the null hypothesis (Iman and Conover, 1983))) but hydrologically it is insignificant, 0.54 versus 0.56. For ET there also is a significant difference between the means of the two data sets ($Z = 4.01$ $P < 0.001$) but the difference in the means, 50.2 versus 47.1 cm, is also not likely to be hydrologically significant.

For mean ET values the steps involved are: 1) create a TIN for (a) the long-term runoff values from the manual map, and (b) the long-term precipitation at the precipitation stations; 2) interpolate long-term precipitation values to the long-term runoff sites and long-term runoff values to the long-term precipitation stations using the TIN's created in 1); 3) calculate, from the interpolated and measured values, an ET value for each of the precipitation stations and runoff sites; 4) sort the runoff and precipitation sites by their MLRA and calculate a mean ET for each MLRA; 5) assign the mean ET values to WY84 precipitation stations based on the MLRA's in which the station occurs; 6) calculate estimated runoff using precipitation values and the mean ET values at each station (estimated R = P - ET); 7) create a TIN using both the estimated runoff at precipitation stations and the gaged runoff; 8) generate a contour map, by linear interpolation, for WY84 runoff using the TIN created in 7). This methodology is diagramed in Figure 12 and will be referred to as the MNLTET procedure. For the mean R/P method the steps involved are: 1) create a TIN for (a) the long-term runoff values from the manual map, and (b) the long-term precipitation at the precipitation stations; 2) interpolate long-term precipitation values to the long-term runoff sites and long-term runoff values to the long-term precipitation stations using the TIN's created in 1); 3) calculate, from the interpolated and measured values, an R/P value for each of the precipitation stations and runoff sites; 4) sort the runoff and precipitation sites by their MLRA and calculate a mean R/P for each MLRA; 5) assign the mean R/P values to WY84 precipitation stations based on the MLRA's in which the station occurs; 6) calculate estimated runoff using precipitation values and the mean R/P values at each station (estimated R = P(R/P)); 7) create a TIN using both the estimated runoff at precipitation stations and the gaged runoff; 8) generate a contour map, by linear interpolation, for WY84 runoff using the TIN created in 7).This methodology is diagramed in Figure 13 and will be referred to as the MNLTRP procedure.

The fifth methodology uses linear regression formulae to predict runoff or ET at precipitation stations. These formulae are based on the relationship between various climatic and physiographic variables and the long-term values of runoff, interpolated from the long-term manual map, and ET, estimated by the water-balance method at

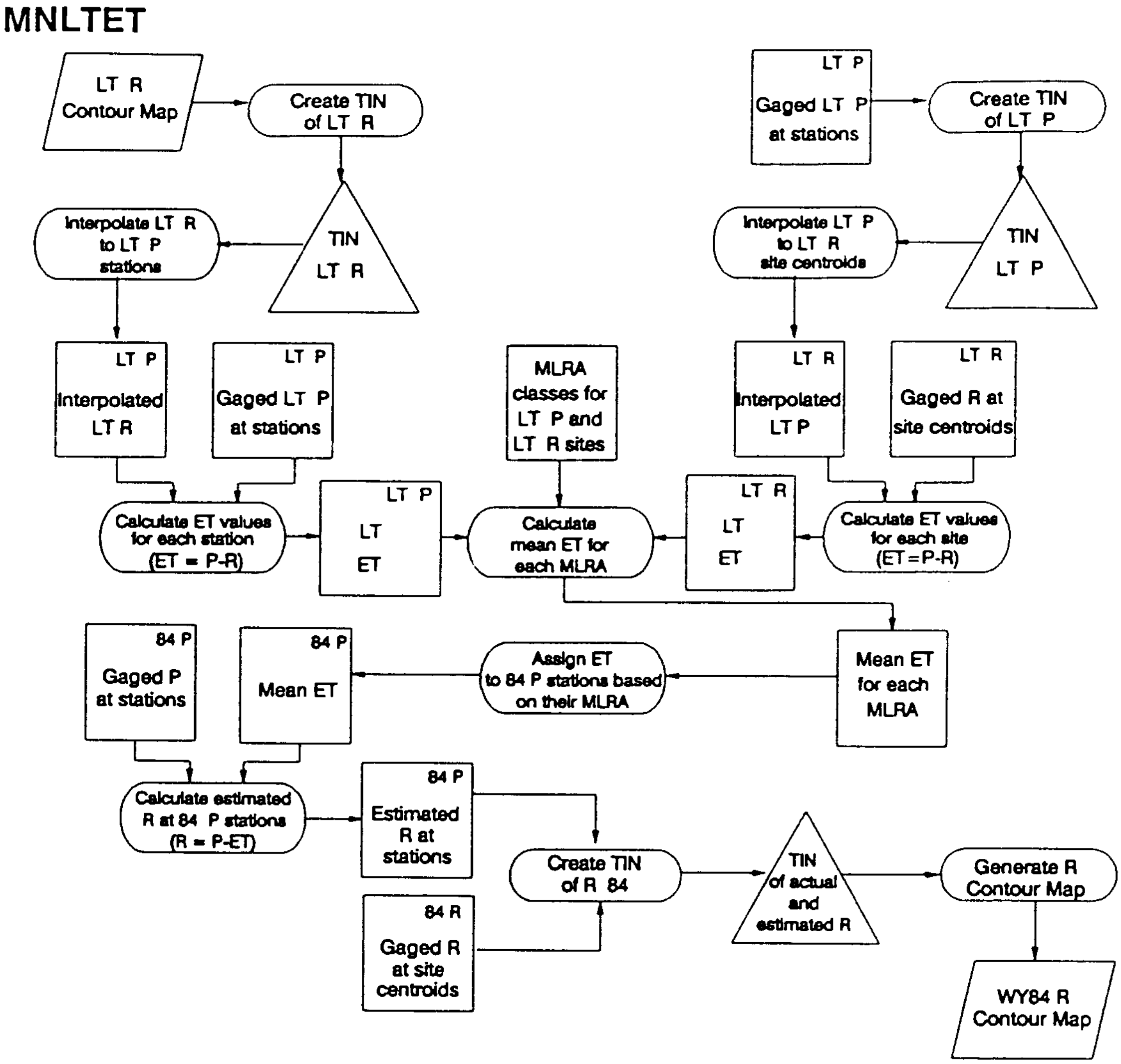


Figure 12. Steps in the Production of a Runoff-Depth Contour Map Using the MNLTET Procedure.

MNLTRP

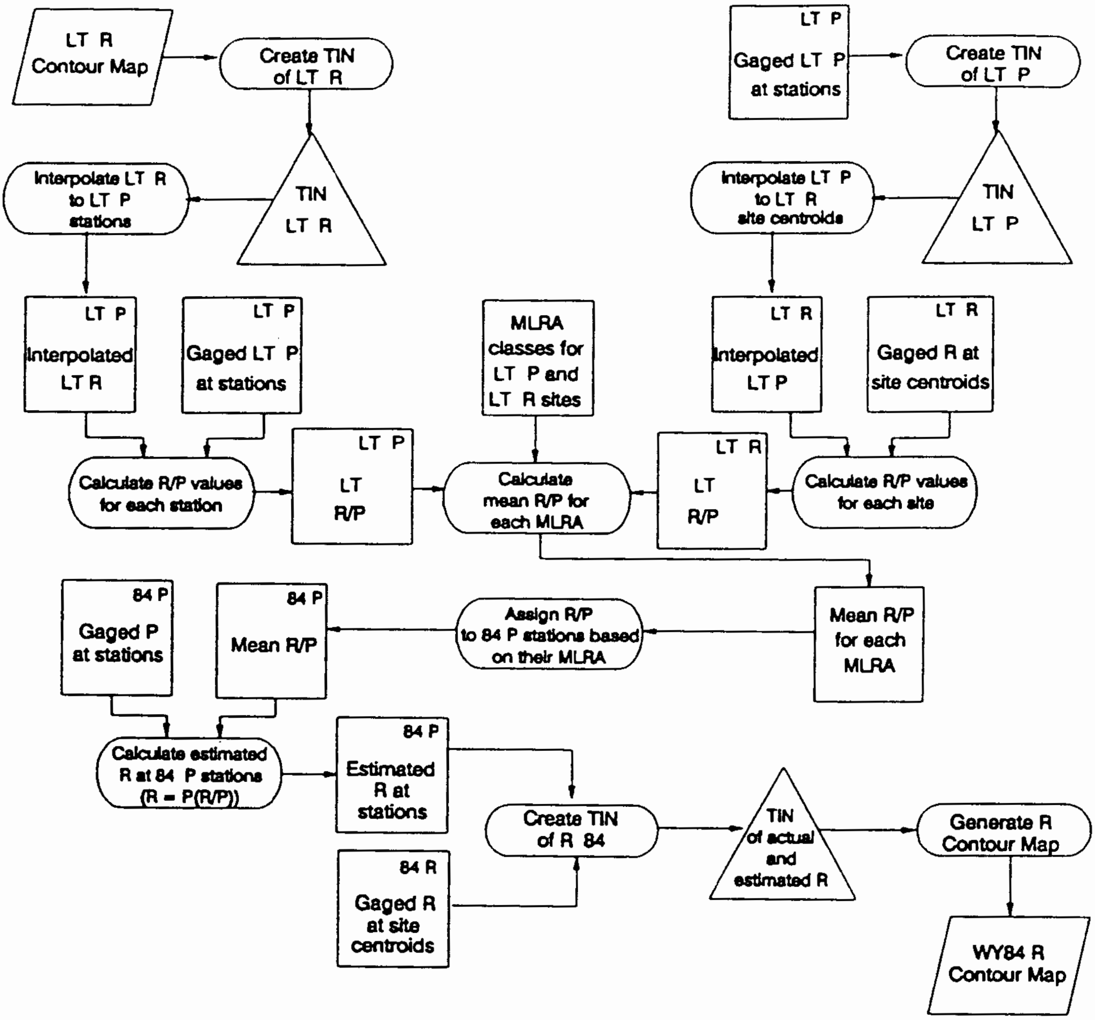


Figure 13. Steps in the Production of a Runoff-Depth Contour Map Using the MNLTRP Procedure.

the long-term precipitation stations. Regression formulae have been used in the past to interpolate runoff values within the time and geographic framework in which the formulae were developed (Lull and Sopper, 1967, Sopper and Lull, 1970, Liebscher, 1972, Dingman, 1981), but no examples of extrapolating a regression formula temporally with runoff data was found in the literature. Regression equations have been used to predict storm runoff (Lee and Bray, 1969), temperature (Lee, 1969) and other climatic variables (Dingman, 1981). Deangelis, *et al.*, (1984) found for a watershed in the Northeast that a single linear relationship exists between precipitation and runoff, even when very wet and dry years were examined. This implies that a relationship defined for a normal period in a region may have validity in wet or dry years. A single regression formula for the region was deemed to be appropriate due to the general regional scale approach of the research, a desire to avoid over-fitting of the regression model produced (Klemes, 1983) and the need for a broad range of data in which to fit the desired estimates (Lee, 1980). Critiques of the use of regression formulae in hydrology include Linsley's (1967) questioning of the ability of the formulae to adequately represent the phenomena especially in mountainous terrain (Mckay and Thomas, 1971, UNESCO/WMO, 1977). These reservations aside, the success of Liebscher (1972) with this methodology and the findings of Deangelis, *et al.*, (1984) warranted its investigation.

For predicting runoff-depth the independent variables used by Liebscher (1972) (*i.e.* annual precipitation, mean annual temperature, and the ratio of summer to winter precipitation) were used because of the availability of the needed data and the variables taking into account the seasonal differences in runoff's response to precipitation (Shelton, 1985). The variables met the 0.15 significance level (*i.e.* a 15% chance of rejecting a variable that would contribute to the predictive power of the model (SAS Institute, Inc., 1985)) to be included in the model which has an R^2 of 0.758. A graph of regression derived and estimated runoff showed no bias or outliers. Plots of studentized residuals also showed no bias. For ET no suitable regression formula was found that used the available data so all available variables that might influence ET were included in a stepwise regression procedure. Five variables (February and April precipitation, May mean temperature, April maximum temperature, and the ratio of summer to winter precipitation) met the 0.15 significance level and were determined to make significant improvements to the model by their F values. The model's R^2 is 0.699. A graph of regression derived and estimated ET showed no bias or outliers. Plots of studentized residuals also showed no bias. For both of the regression analyses the Mt. Washington precipitation site was not included in determining the regression formula after an examination of scatter plots showed the site to be an outlier.

The steps in the ET regression are: 1) create a TIN for the long-term manual runoff map; 2) interpolate long-term runoff to the long-term precipitation stations using the TIN created in 1); 3) calculate long-term ET from the interpolated and measured values; 4) generate a regression formula to predict long-term ET estimated in 3), using long-term climatic data at precipitation stations in a stepwise regression procedure; 5) calculate estimated ET, using the regression formula developed in 4) and the WY84 climatic data at each precipitation station; 6) calculate estimated runoff using precipitation values and the estimated ET at each station (estimated R = P - ET); 7) create a TIN using both the estimated runoff at precipitation stations and the gaged runoff; 8) generate a contour map, by linear interpolation, for WY84 runoff using the TIN created in 7). This method is diagramed in Figure 14 and will be referred to as the REG_ET procedure. The steps involved in the runoff regression method are: 1) create a TIN for the long-term manual runoff map; 2) interpolate long-term runoff to the long-term precipitation stations using the TIN created in 1); 3) generate a regression formula to predict long-term runoff estimated in 2), using long-term climatic data at precipitation stations and the relationship developed by Liebscher (1972) (*i.e.* runoff is a function of mean annual temperature, mean annual precipitation, and the ratio of summer to winter precipitation); 4) calculate estimated runoff, using the regression formula developed in 3) and the WY84 climatic data at each precipitation station; 5) create a TIN using both the estimated runoff at precipitation stations and the gaged runoff; 6) generate a contour map, by linear interpolation, for WY84 runoff using the TIN created in 5). This method is diagramed in Figure 15 and will be referred to as the REG_R procedure.

The sixth methodology uses the mean MLRA values of WY84 R/P ratios determined by interpolating WY84 runoff from gaged centroid sites to the precipitation stations and WY84 precipitation from the stations to the runoff centroids. No statistical difference was found between the means using the two methods (0.605 vs. 0.604, Z = .10 P = .92). Lull and Sopper (1966) noted a marked

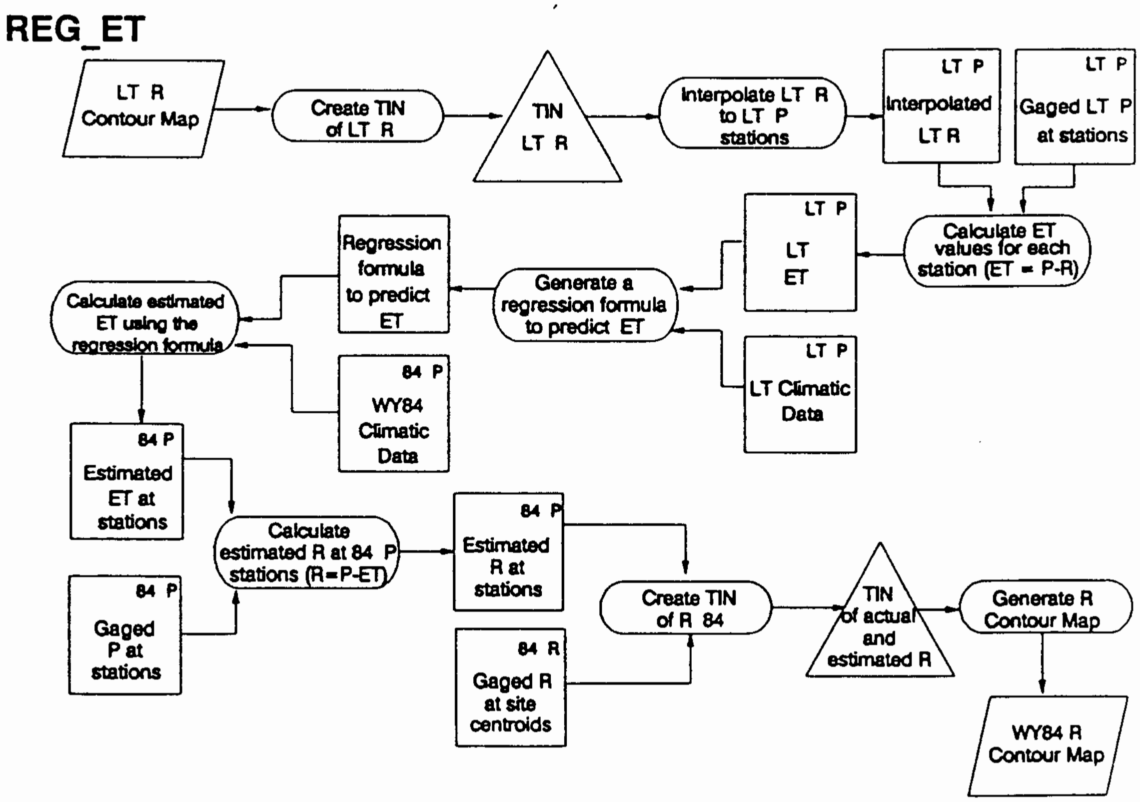


Figure 14. Steps in the Production of a Runoff-Depth Contour Map Using the REG_ET Procedure.

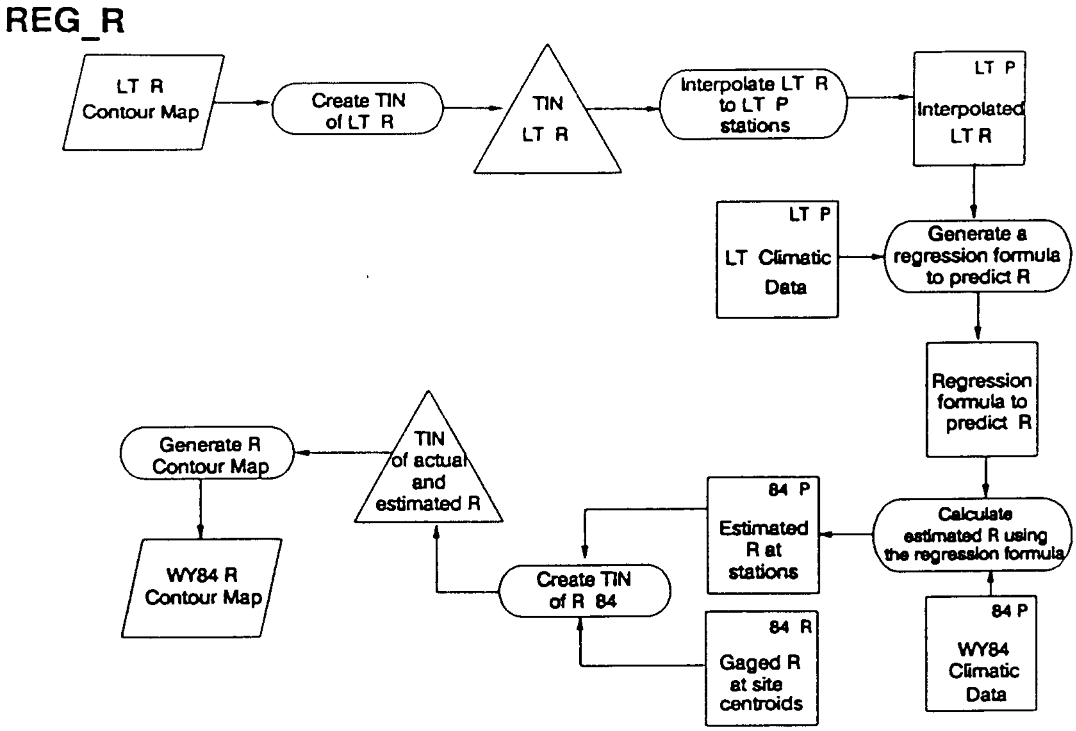


Figure 15. Steps in the Production of a Runoff-Depth Contour Map Using the REG_R Procedure.

decrease in the correlation of runoff to precipitation in the NE when paired sites (precipitation:runoff) are more than 13 km (8 miles) apart. However scatter-plots of the R/P values versus distance to the nearest gage of the opposing type showed no trends and no differences between the two methods (*i.e.* runoff to precipitation stations, precipitation to runoff sites). For WY84 precipitation values interpolated to runoff sites a statistically significant difference (Z = 2.26 P = .024) was found between the mean R/P of sites less than 13 km (0.595) and those greater than 13 km (.619); but these values are not hydrologically significant. For WY84 runoff interpolations to precipitation stations no statistical difference (Z = 0.636 P = .52) was found between the two groups (less-than 13 km .602, greater-than 13 km .608).

The steps involved in this procedure are: 1) create a TIN for (a) the WY84 runoff values from the gaged runoff (as assigned to the centroid of the basin in which the basin occurs), and (b) WY84 precipitation at the precipitation stations; 2) interpolate WY84 precipitation values to WY84 runoff sites and WY84 runoff values to WY84 precipitation stations from the TIN's created in 1); 3) calculate, from the interpolated and measured values, R/P for each of the precipitation stations and runoff sites; 4) sort the runoff and precipitation sites by their MLRA and calculate a mean R/P for each MLRA; assign the mean R/P values to the WY84 precipitation stations based on the MLRA in which the station occur; 6) calculate estimated runoff using precipitation values and the mean R/P values at each station (estimated R = P(R/P)); 7) produce a TIN using both the estimated runoff at precipitation stations and the gaged runoff; 8) produce a contour map, by linear interpolation, for WY84 runoff using the TIN created in 7). This method is diagramed in Figure 16 and will be referred to as the MN84RP procedure.

SELECTION OF FIVE PROCEDURES TO BE EXAMINED BY AN UNCERTAINTY ANALYSIS

Visual Comparison

Eight maps were produced by the eight different procedures described above (Plates 3-10). The maps were first visually compared to the expertly drawn runoff-depth map produced by Graczyk, *et al.* (1987) (MAN84) (Plate 2) to note any general patterns or agreement/disagreement in the procedure maps as compared to the MAN84 map. The first general trend noted was the lack of strong variations among the automated procedures as far as the general pattern of runoff-depth depicted (Figure 17). This is probably due to the use of the same gaged runoff sites in all the procedures.

Upon closer examination a spikier, less generalized surface became apparent when comparing the LTET and LTRP maps to the MAN84, MNLTET, and MNLTRP maps. Both the LTRP and MNLTRP maps appear to underestimate runoff, especially along the Atlantic coast. This is probably due to the much higher than average precipitation experienced by this area in WY84 (USGS, 1985). This suggests that the assumption, (*i.e.* R/P is constant over time) that the LTRP and MNLTRP maps are based on is false. This was supported by a comparison of long-term and WY84 R/P values at precipitation and runoff sites that contain values for both time periods (n=460). The runoff-to-precipitation ratio was calculated for the

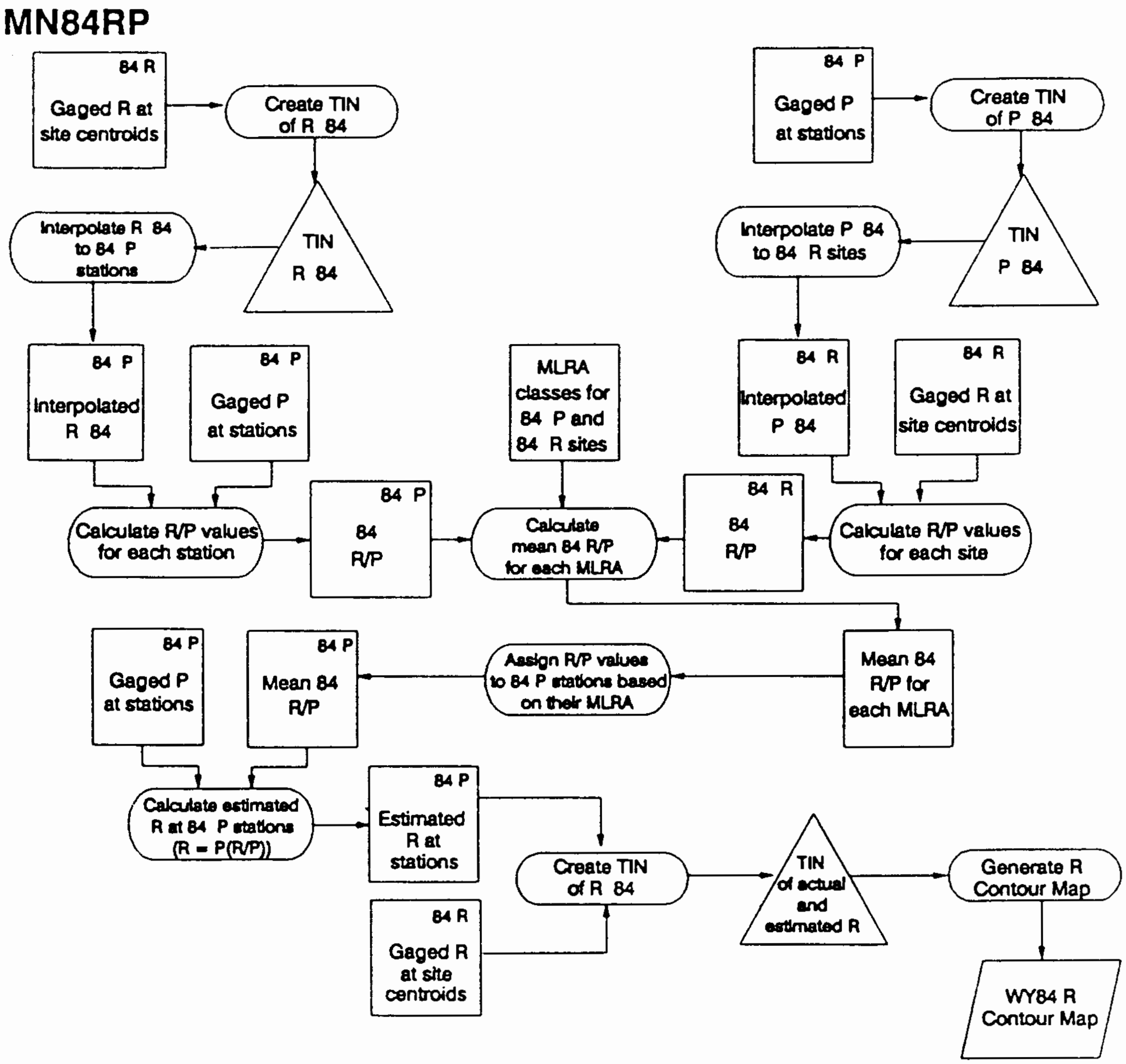


Figure 16. Steps in the Production of a Runoff-Depth Contour Map Using the MN84RP Procedure.

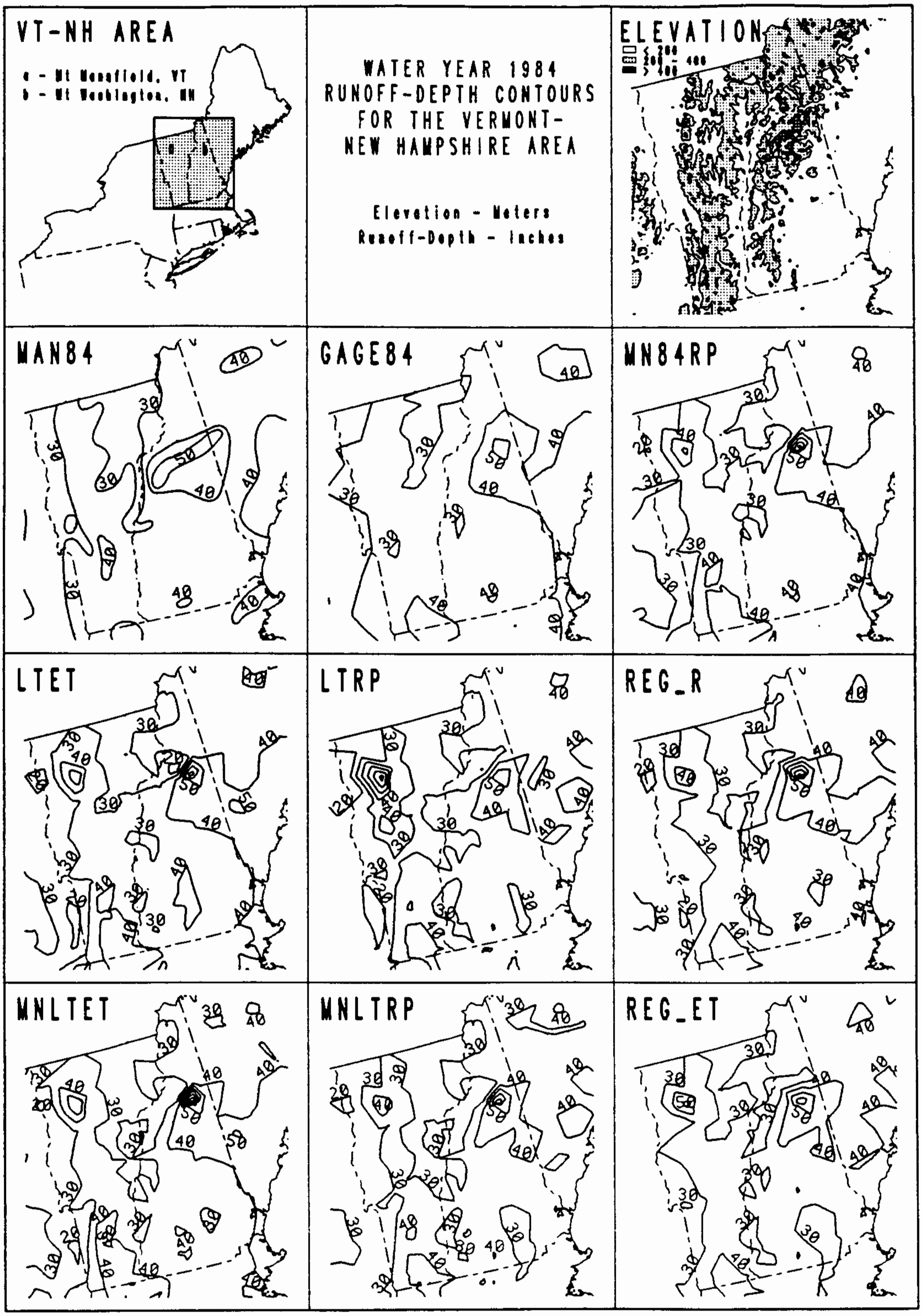


Figure 17. Comparison of Eight Procedure Derived Runoff-Depth Contour Maps in the VT-NH Sub-Area of the Northeast Region.

precipitation stations by interpolation from the given time periods manual method map while for runoff sites precipitation values were interpolated from precipitation stations (Table IV). The difference in the means was found to be significant at the .0001 level by both a T-test and a signed rank test. The differences are also hydrologically significant. The REG_R and REG_ET maps also appear to underestimate runoff over the region. This may be due to the inadequacies of the regression models, inappropriateness of temporal extrapolation, or biases in the climatological or gaged data. Random errors in the measurement of the climatological data inputs could also explain the noted bias (Weber, *et al.*, 1973). The GAGE84 map follows the general trend of the MAN84 map, but lacks the detail of the MAN84 map, especially in the mountainous areas. The MN84RP map is a fairly close match to the MAN84 map, both in general pattern and values. For all the procedures there are some minor variations from the MAN84 map which may be due to the increased resolution or noise caused by using estimated runoff values.

TABLE IV

ESTIMATED R/P AT CORRESPONDING (LONG-TERM AND WY84) PRECIPITATION AND RUNOFF SITES[*]

	Mean	Standard Deviation
long-term R/P	.548	.080
WY84 R/P	.614	.091
WY84 R/P - long-term R/P	.065	.079

[*] n=460

Statistical Comparison

A statistical comparison of the methods was also conducted by comparing estimated and interpolated values of runoff at the WY84 precipitation sites. These values are summarized in Table V. The general trend of underestimation by LTRP, MNLTRP, REG_ET, and REG_R are confirmed by the statistical analysis. A trend of overestimation by the LTET and MNLTET procedures is also apparent. This suggests that the simplifying assumption (*i.e.* ET is constant over time) that the LTET and MNLTET procedures are based on may be inappropriate. This was confirmed by comparing long-term and WY84 ET at precipitation and runoff sites that correspond between the two time periods (n=460). ET was calculated by interpolating runoff from the appropriate runoff-depth maps, long-term and WY84, to the precipitation sites and then subtracting the runoff value from the precipitation value. For the runoff sites precipitation values were interpolated from the precipitation stations and a similar calculation made (Table VI). The difference in means are significantly different at the .001 level with both the T-test and the signed rank test. The GAGE84 and MN84RP methods give the closest approximation to the MAN84 map using this analysis. A comparison of the means of the estimated runoff at precipitation stations and interpolated values from MAN84 was conducted. All of the procedures means were significantly different at the .001 level except for GAGE84 (P(T) = .92 P(S) = .65) and MN84RP (P(T) = .35 P(S) = .38).

TABLE V

ESTIMATED RUNOFF AT WATER-YEAR 1984 NCDC PRECIPITATION STATIONS

Method	n	Mean	Standard Deviation	Minimum	Maximum	Standard Error of the Mean
Interpolated Values:						
MAN84	394	83.82*	18.06*	30.13*	127.00*	0.91
GAGE84	381	83.59	18.52	30.56	146.70	0.95
Estimated Values:						
LTET	396	86.87	21.41	33.14	207.44	1.08
MNLTET	405	87.37	24.24	32.95	293.34	1.20
LTRP	396	73.32	16.45	35.73	148.63	0.83
MNLTRP	405	74.10	15.87	38.32	209.70	0.79
REG_ET	225	74.67	17.84	37.82	181.36	1.19
REG_R	217	76.60	18.54	34.97	225.37	1.26
MN84RP	397	84.00	20.70	37.50	229.29	1.04

*Cm

TABLE VI

ESTIMATED ET* AT CORRESPONDING (LONG-TERM AND WY84) PRECIPITATION AND RUNOFF SITES**

	Mean	Standard Deviation
long-term ET	49.44	10.80
WY84 ET	54.49	18.81
WY84 ET - long-term ET	5.05	14.67

*Cm
**n=460

The rejection of the R/P and ET being constant assumptions are not conclusive at this point since unknown biases from the use of the manual maps may be involved.

These conclusions will be further tested in Chapter IV with the comparison of estimates made from maps created based on these assumptions to actual gaged values with an uncertainty analysis.

Choice of Procedures Used in the Uncertainty Analysis

To reduce the amount of work involved in the uncertainty analysis a representative subset of the eight procedures was chosen. Five procedures were selected to conduct the uncertainty analysis on using the above visual and statistical comparisons. The GAGE84 method was chosen to represent the simplest and most straightforward automated procedure available. MNLTET and MNLTRP were chosen over LTET and LTRP mainly due to the better visual fit to the MAN84 map. REG_R was chosen as the regression method to be tested because of the simpler formula used and its slightly better visual and statistical fit to the MAN84 map as compared to REG_ET. MN84RP was chosen because of its close visual and statistical match to MAN84.

Summary of Findings

A statistical comparison of the means of the estimated runoff-depth at WY84 precipitation stations shows the GAGE84 and MN84RP methods having the closest approximation to the values interpolated from MAN84. This indicates that the working hypothesis that using information gained from a long-term expert map would improve the accuracy of a given water-year's map is inappropriate since visually and statistically none of the maps using the long-term data appear to be superior to those using only WY84 data. This conclusion will be further tested in Chapter IV with an uncertainty analysis. Depending on the accuracy desired for the project at hand all of the procedures above could be considered acceptable. The MN84RP method visually and statistically appears to give the closest approximation to the manually produced map for WY84.

CHAPTER IV

UNCERTAINTY ANALYSIS

INTRODUCTION

A subset of the automated procedures described in Chapter III (GAGE84, MNLTET, MNLTRP, REG_R, and MN84RP) was compared to the manual method using an uncertainty analysis of runoff estimates. An uncertainty analysis is the withholding of data sites from a runoff map's creation for later use in a comparison of values obtained by interpolation from the generated maps to the actual gaged data. The results of an uncertainty analysis conducted on a long-term average runoff-depth map conducted by Rochelle, *et al.* (1989) will define the accuracy of the manual procedures. The uncertainty analysis of the automated procedures consisted of four steps. The first step was the selection of the data sites to be withheld from the contour map generation. The second was the generation of the contour maps. The third step was the interpolation of runoff-depth from the maps generated to the withheld sites. The fourth was the calculation of the interpolation errors by subtracting interpolated (estimated) runoff from gaged runoff at each site. A statistical summary and analysis was then conducted on these results as well as an examination for possible biases in estimated runoff and interpolation errors.

METHODOLOGIES

The first step in the uncertainty analysis was the choice of the sites to be withheld. Of the 441 U.S. Geological Survey (USGS) Water-Year 1984 (WY84) runoff sites in the region of study 50 sites were withheld. This number approximates the number of sites used by Rochelle, *et al.* (1989) in the Northeast (NE) portion of their study of the eastern U.S. (approximately 40). Results using a withheld-site set of 50 are comparable to the results from the 97 sites used in Rochelle, *et al.* (1989) (Stevens, 1991).

In selecting the 50 withheld sites (Figure 18) it was desirable to have the sample reflect the spatial properties of the gaged site population; that is being sparse where stations are sparse and dense were stations are dense. Although in the long run strict random sampling will have this property, individual samples tend towards being poor representations of the spatial distribution. Some restrictions were therefore placed on the selection of the withheld sites. This was done with the use of a spatially systematic random sample (*e.g.* Bickford, *et al.*, 1963) (Stevens, 1991, Stevens, *et al.*, 1991). The sampling procedure used was based on spatial clustering similar to that used in the National Lake Survey (NLS) (Overton, 1987), except that sites were selected with an algorithm rather than subjectively as the NLS did. The spatial extent of the resource (gaged sites) was divided into compact clusters of points such that approximately an equal number of samples (*i.e.* withheld sites) were taken from each cluster. Clusters were formed by an algorithm that selects a point in the population that is furthest from the spatial center of the population. The points near this cluster

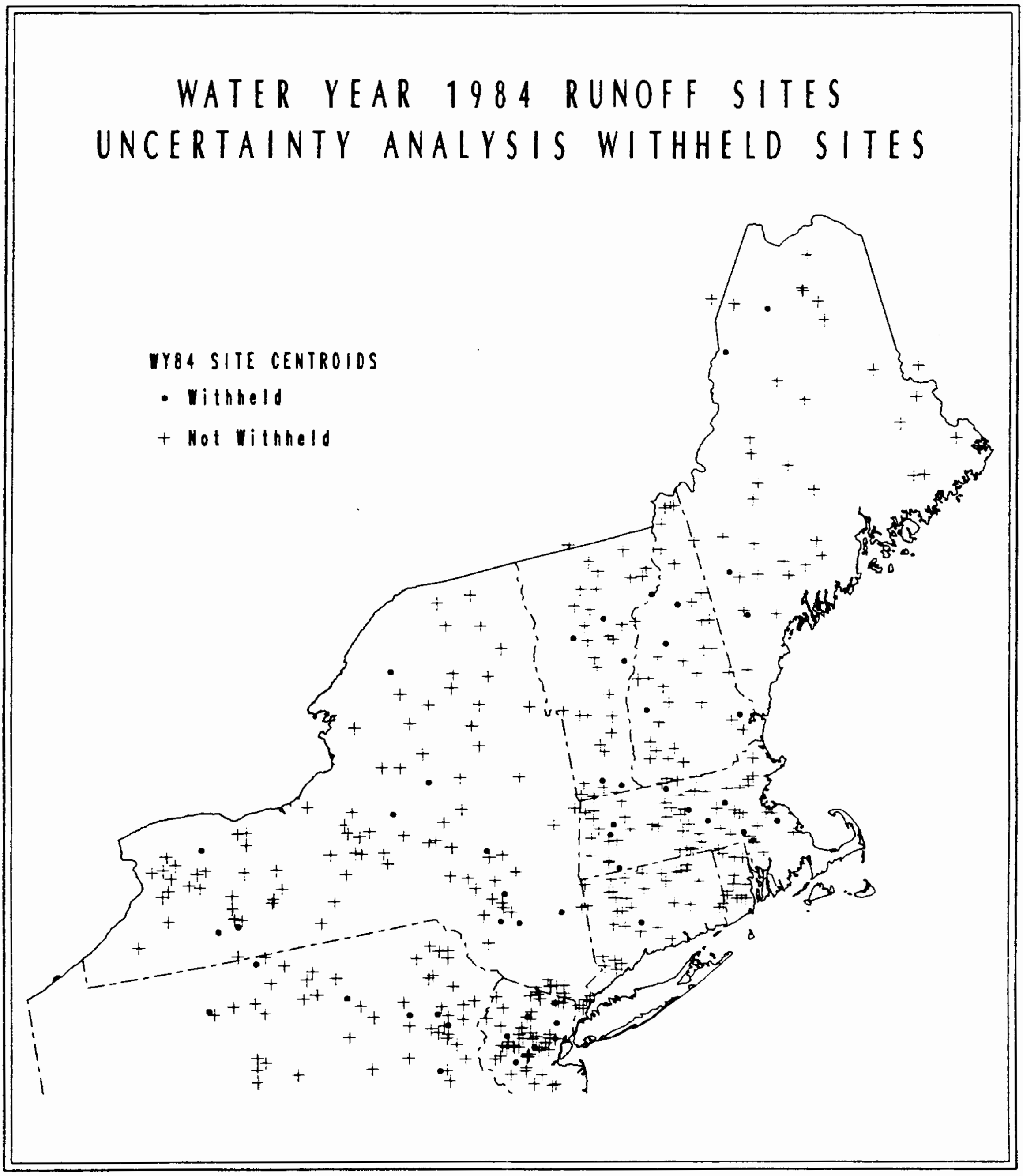


Figure 18. Uncertainty Analysis Withheld Water-Year 1984 Gaged Runoff-Depth Sites.

seed that have not been selected were assigned to this cluster until the desired cluster size was reached. The process was then repeated with the spatial extent of the populations reduced by the exclusion of the points already selected (Stevens, 1991).

Due to statistical considerations (*i.e.* spatial restrictions, problems in variance estimation) the sample size per cluster is best when it is approximately two. Two sites therefore were selected from each of 25 clusters comprised of roughly 18 sites each. Due to 441 not being divisible by 18 some clusters had fewer than 18 sites, but this moderate variation in cluster size was deemed to be of little consequence as long as the target size was near two (Stevens, 1991, Stevens, *et al.*, 1991).

After the site selection the next step was the generation of the contour maps for each of the procedures (GAGE84, MNLTET, MNLTRP, REG_R, MN84RP) without using the 50 withheld sites. This included withholding the WY84 runoff data from the generation of the mean regional R/P values used in the MN84RP procedure. For all of the procedures the 50 sites were withheld from the generation of the TIN (*i.e.* Triangulated Irregular Network (ESRI, 1986)) created from estimated and actual runoff-depth values, used to create the runoff-depth contours. In the third step a TIN was created from these contours and estimated runoff-depth values were linearly interpolated to the withheld sites. The fourth step was the calculation of interpolation error values by subtracting gaged from estimated runoff at each withheld site. These values are presented in Appendix C.

RESULTS AND DISCUSSION

Interpolation Errors

Summary statistics (*i.e.* mean, standard deviation, *etc.*) were generated from the interpolation error values calculated in the uncertainty analysis. These were then compared to the results of Rochelle, *et al.* (1989) (Table VII). Rochelle, *et al.* (1989) 'CNTR' method, a manual method which interpolates to the gaged sites centroid, is equivalent to the GIS driven linear interpolation used in this thesis. The mean error for the REG_R and MN84RP procedures, both for absolute and percentage interpolation errors, yielded the best results and the closest equivalence to the manual procedure and also showed a marked improvement over the simple interpolation procedure (GAGE84).

TABLE VII

INTERPOLATION ERROR DESCRIPTIVE STATISTICS FOR THE 50 WITHHELD RUNOFF SITES

Method	Population Mean	Standard Error of the Mean	Standard Deviation	Population Mean (Percent)	Standard Error of the Mean (Percent)	Standard Deviation (Percent)
Manual**	1.54*	0.88*	8.53*	0.90	1.47	14.21
GAGE84	-1.60	1.60	11.33	-3.23	2.06	14.57
MNLTET	-4.45	2.43	17.22	-6.34	2.72	19.22
MNLTRP	4.20	1.74	12.31	3.32	1.95	13.82
REG_R	0.48	1.82	12.87	-0.74	2.08	14.72
MN84RP	-0.37	1.67	11.83	-1.76	1.96	13.83

* Cm.

**Manual(CNTR) method, Source: Rochelle, *et al.*, (1989) A box-and-whisker diagram of the interpolation errors is presented in Figure 19. The REG_R, MN84RP, and GAGE84 methods show the best grouping of values near zero. A bias towards overestimation by the MNLTET method and underestimation by the MNLTRP method is also apparent.

Empirical distribution function (EDF) graphs are commonly used to display the cumulative relative frequency of a sample (Iman and Conover (1983)). These graphs display the portion of the sample values, on the vertical axis, that are less than or equal to the sample value presented on the horizontal axis. EDF's of interpolation error values for the five procedures are presented in Figure 20. REG_R, MN84RP, and GAGE84 have the steepest slopes centered on an error of zero of the five tested showing a large number of sites with an error near zero. A bias towards overestimation using MNLTET is apparent in the graph from its being off-center of the zero value. All of the procedures show a marked increase in absolute error towards the tails of their distributions. This pattern may be due to the general regionalization algorithms used by the procedures. Watersheds that are atypical for a region will not be handled as well by the algorithms used and thus will have larger interpolation errors (Church, 1991). The general pattern of the EDF's is similar to that found by Rochelle, *et al.* (1989) (Figure 21) for the long-term runoff-depth map of the eastern United States, although the absolute errors are greater for WY84 than the long-term error's found by Rochelle, *et al.* (1989). This is probably due to the increase in runoff-depth in WY84 (*i.e.* a mean of 141%) as compared to the long-

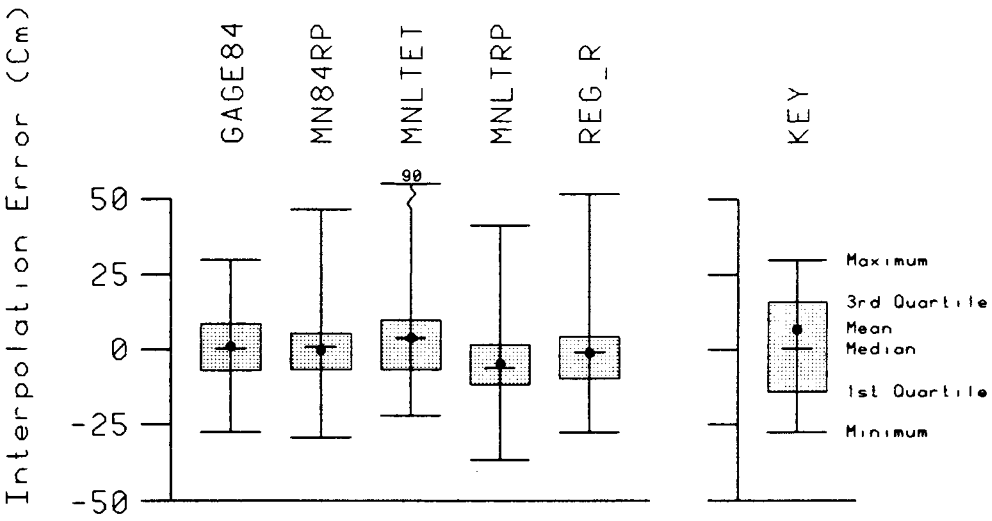
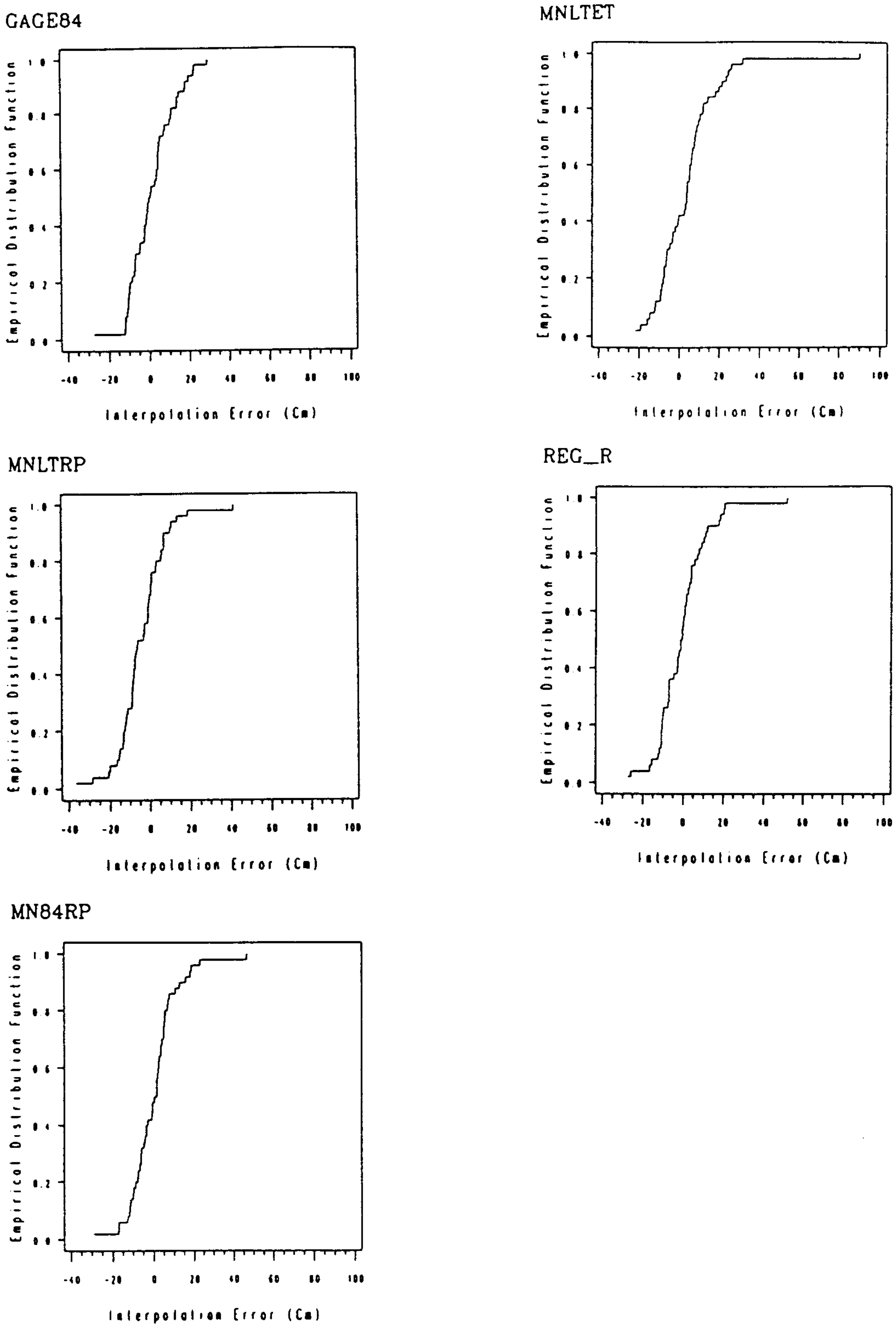


Figure 19. Box-and-Whisker Diagram of Absolute Interpolation Errors (Cm) for the GAGE84, MN84RP, MNLTET, MNLTRP, and REG_R Procedures.



<u>Figure 20.</u> Absolute Interpolation Error (Cm) EDFs for the GAGE84, MNLTET, MNLTRP, REG_R, and MN84RP Procedures.

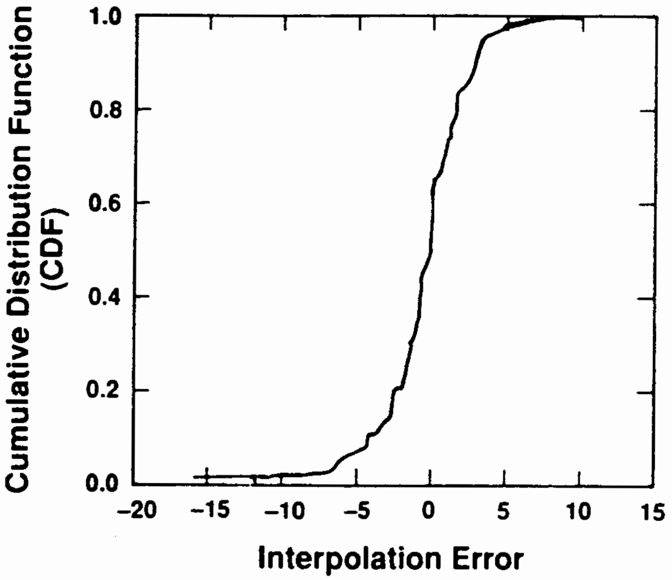


Figure 21. Cumulative Distribution Function of the Absolute Interpolation Error (Gaged - Estimated Runoff) (Cm) of a Long-Term Manual Method Map of the Eastern U.S.. (Source: Rochelle, *et al.*, 1989.)

term average, although other factors including possible defects in the procedures may be contributing to this effect.

Interpolation error values were tested for the significance of their means from zero (Table VIII). A T-test, which requires that the distribution of the variable to be tested is normal, is the test usually used for this purpose (Iman and Conover 1983). A signed rank test, which does not require a normal distribution (Iman and Conover, 1983), was used since none of the distributions of the procedures interpolation errors were normal. MNLTRP was the only method whose mean interpolation error, both absolute and percentage, was shown by the signed rank test to be significantly different from zero. The bias is probably due to this procedure being based on the apparently false assumption that R/P remains constant over time.

TABLE VIII

SIGNED RANK TEST FOR THE DIFFERENCE IN MEAN INTERPOLATION ERROR BEING SIGNIFICANTLY DIFFERENT FROM ZERO

	Absolute Interpolation Error		Percentage Interpolation Error	
Method	Sgn Rank	P(S)	Sgn Rank	P(S)
GAGE84	70.5	0.50	78.5	0.45
MNLTET	153.5	0.14	177.5	0.09
MNLTRP	-294.5	<.01	-246.5	0.02
REG_R	-80.5	0.44	-56.5	0.59
MN84RP	-20.5	0.85	18.5	0.86

A visual inspection of mapped absolute interpolation errors (Figures 22-27) was conducted to examine if a relationship exists between high interpolation error withheld sites and sites where the manual procedure map generalized the contours.

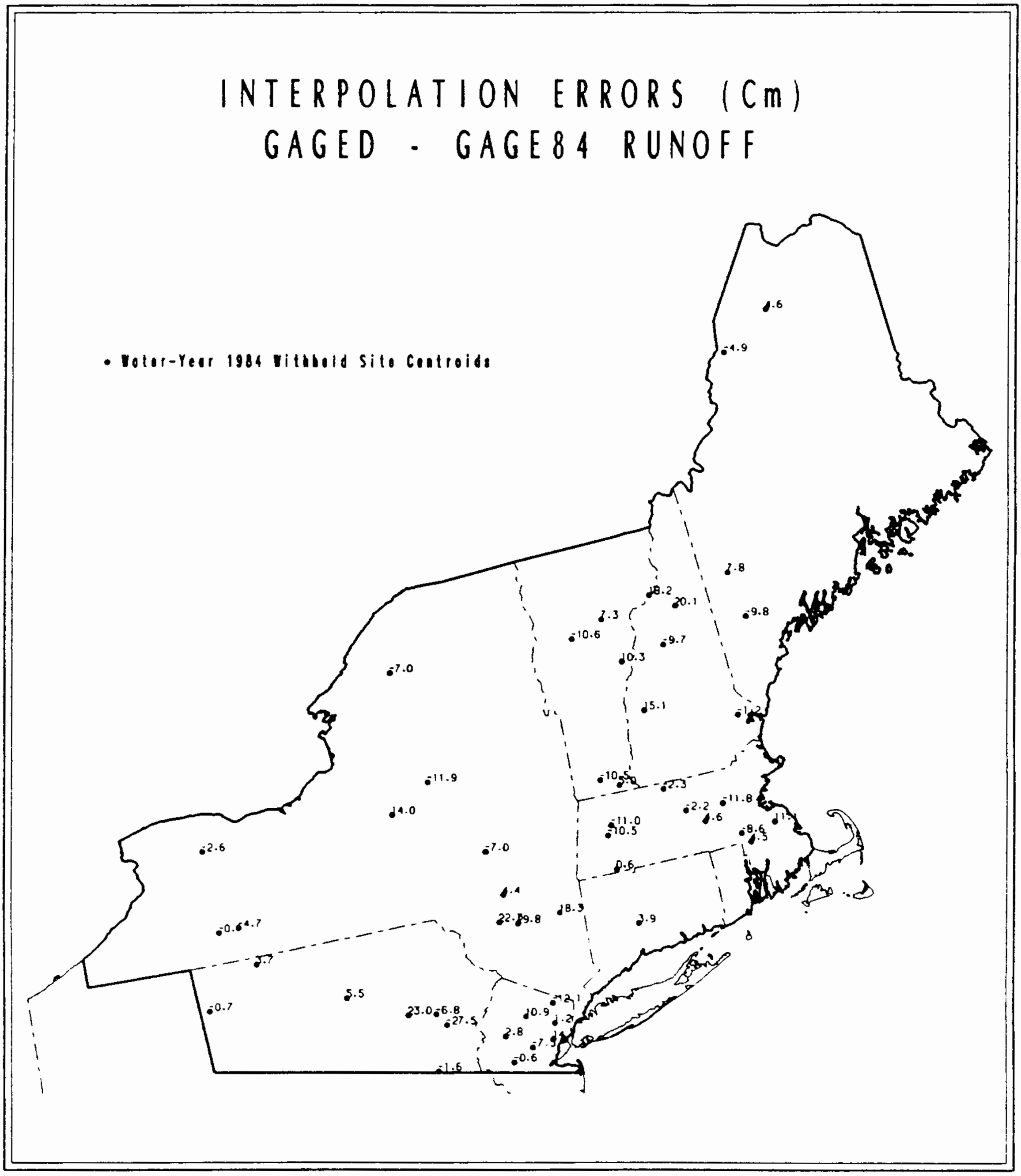


Figure 22. GAGE84 Absolute (Cm) Interpolation Errors at the Withheld Sites.

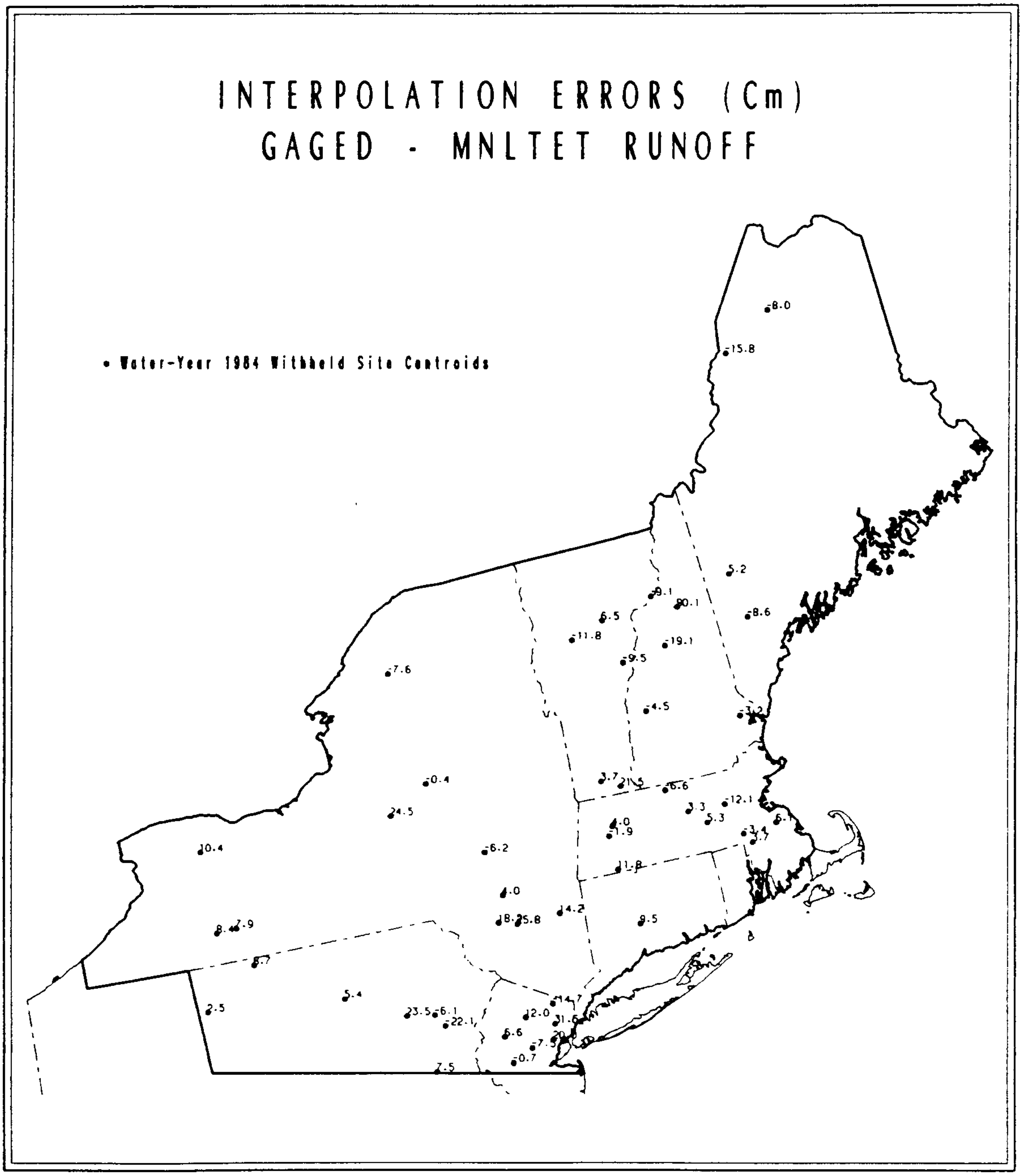


Figure 23. MNLTET Absolute (Cm) Interpolation Errors at the Withheld Sites.

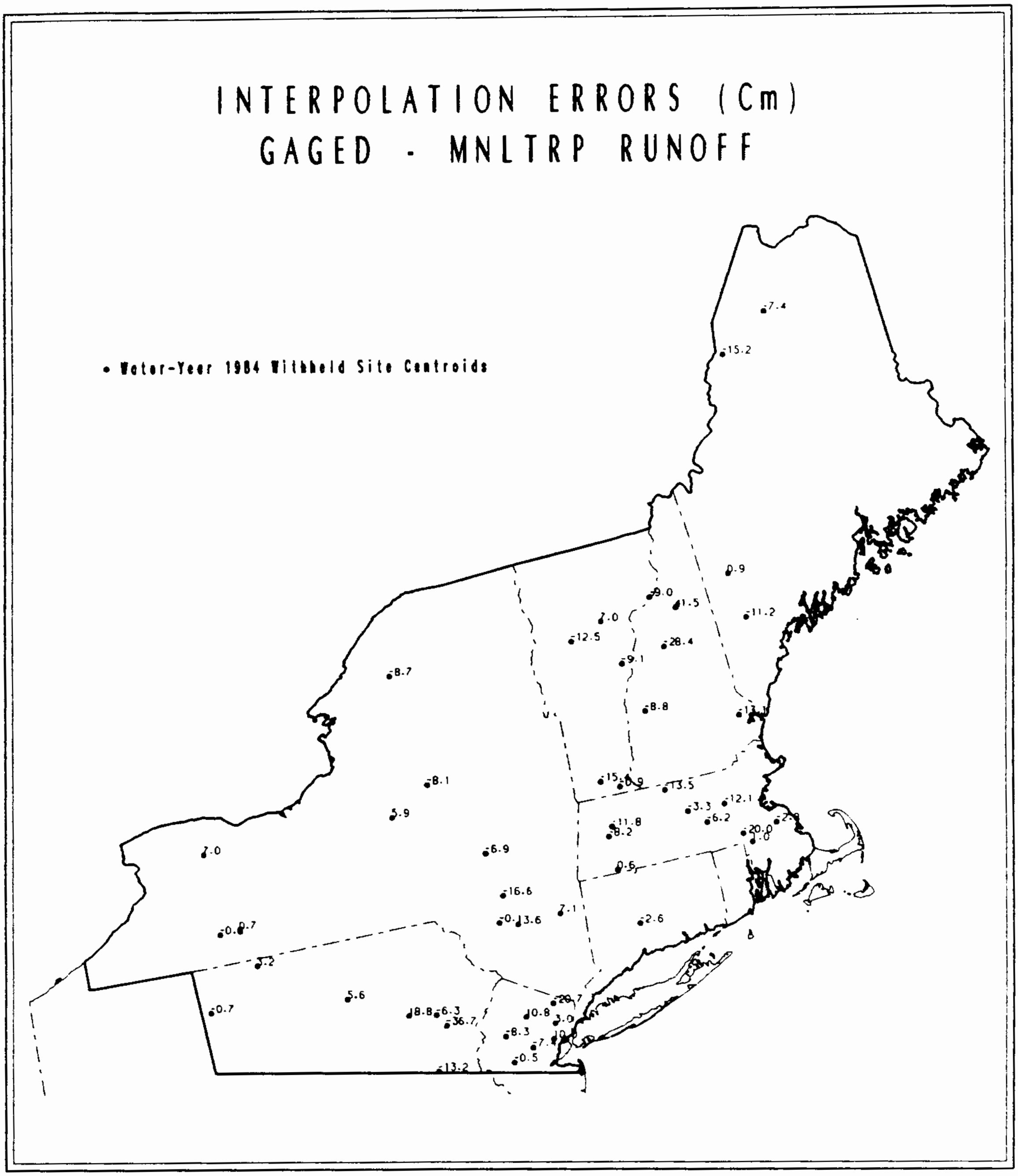


Figure 24. MNLTRP Absolute (Cm) Interpolation Errors at the Withheld Sites.

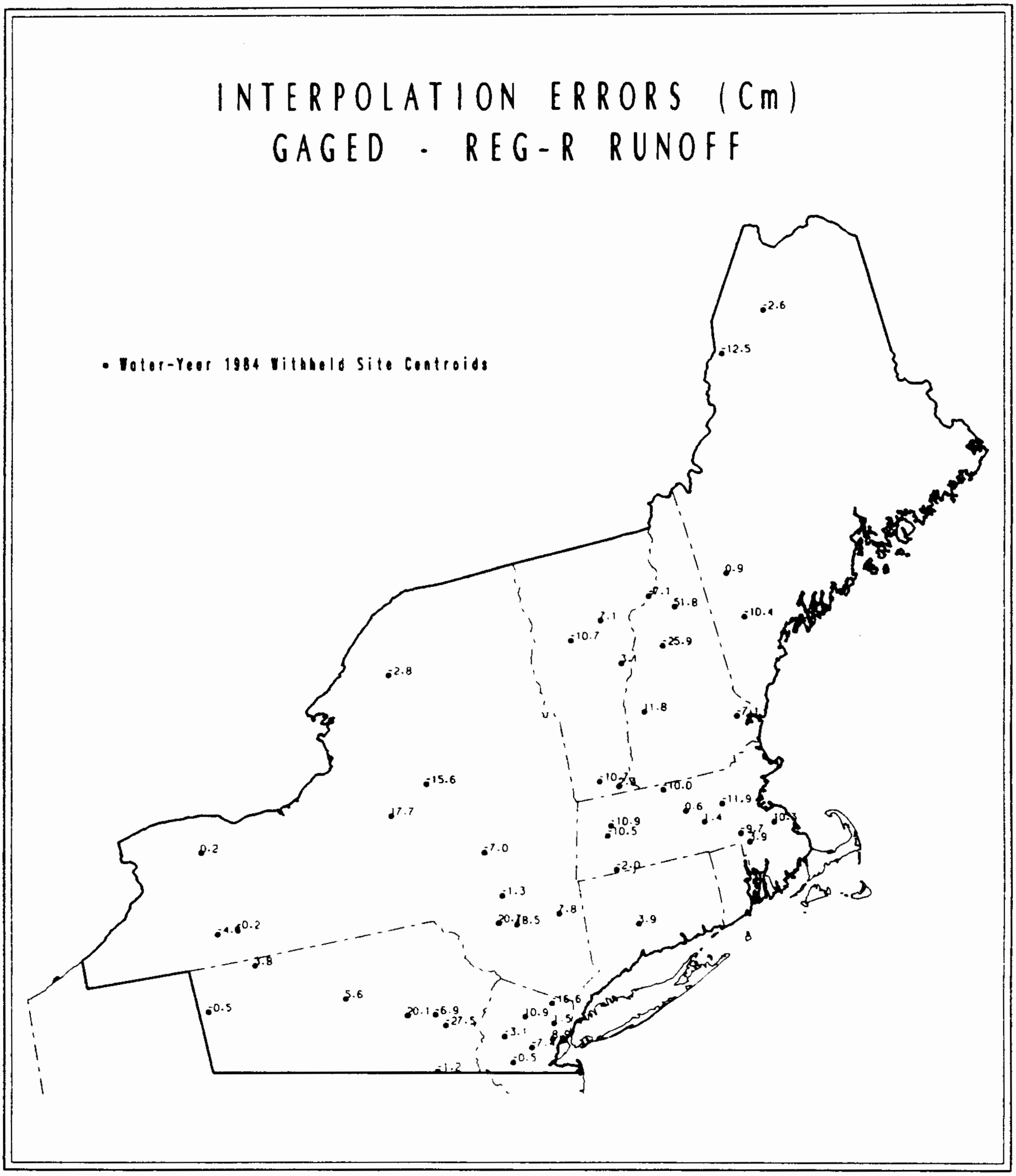


Figure 25. REG_R Absolute (Cm) Interpolation Errors at the Withheld Sites.

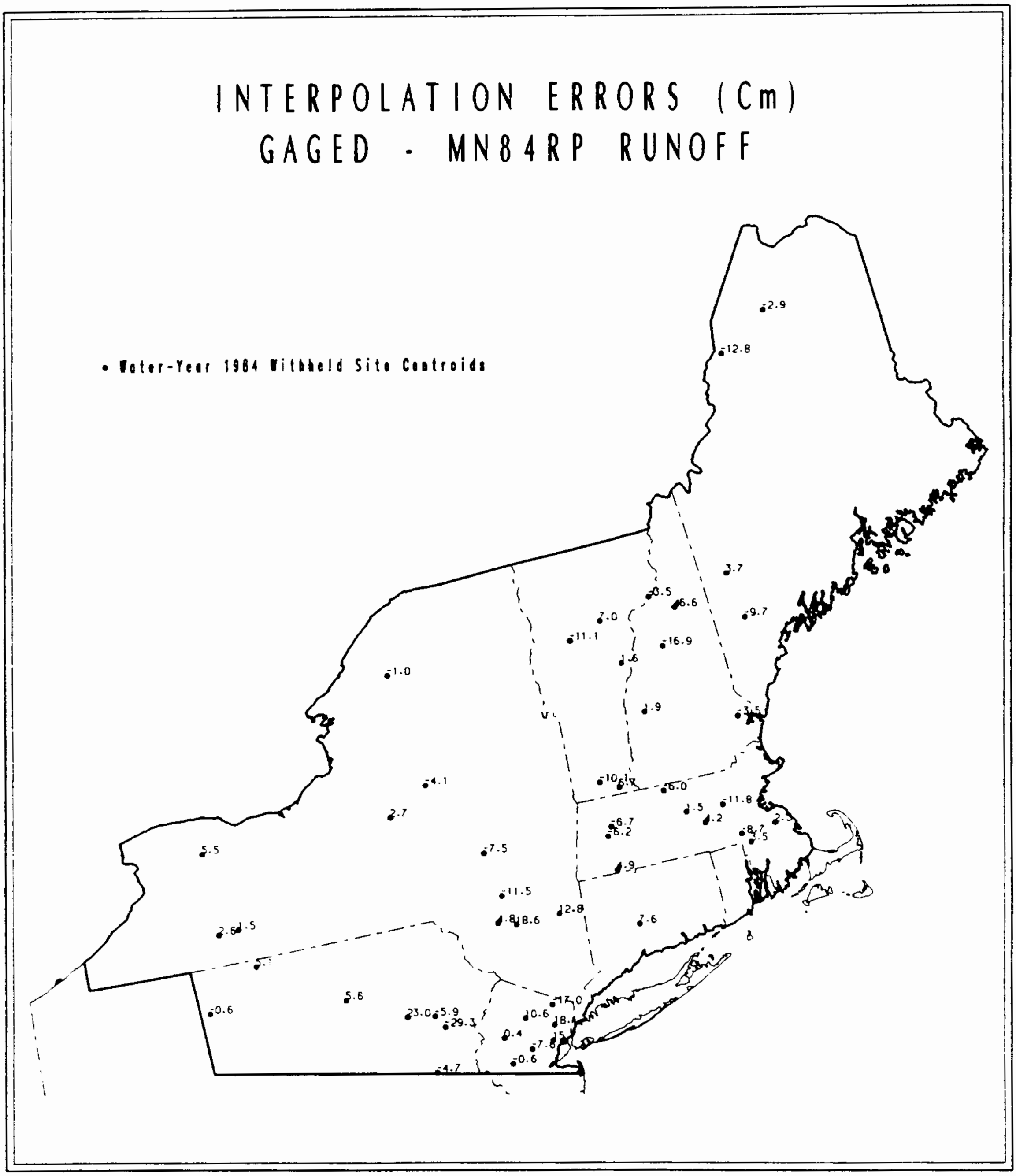


Figure 26. MN84RP Absolute (Cm) Interpolation Errors at the Withheld Sites.

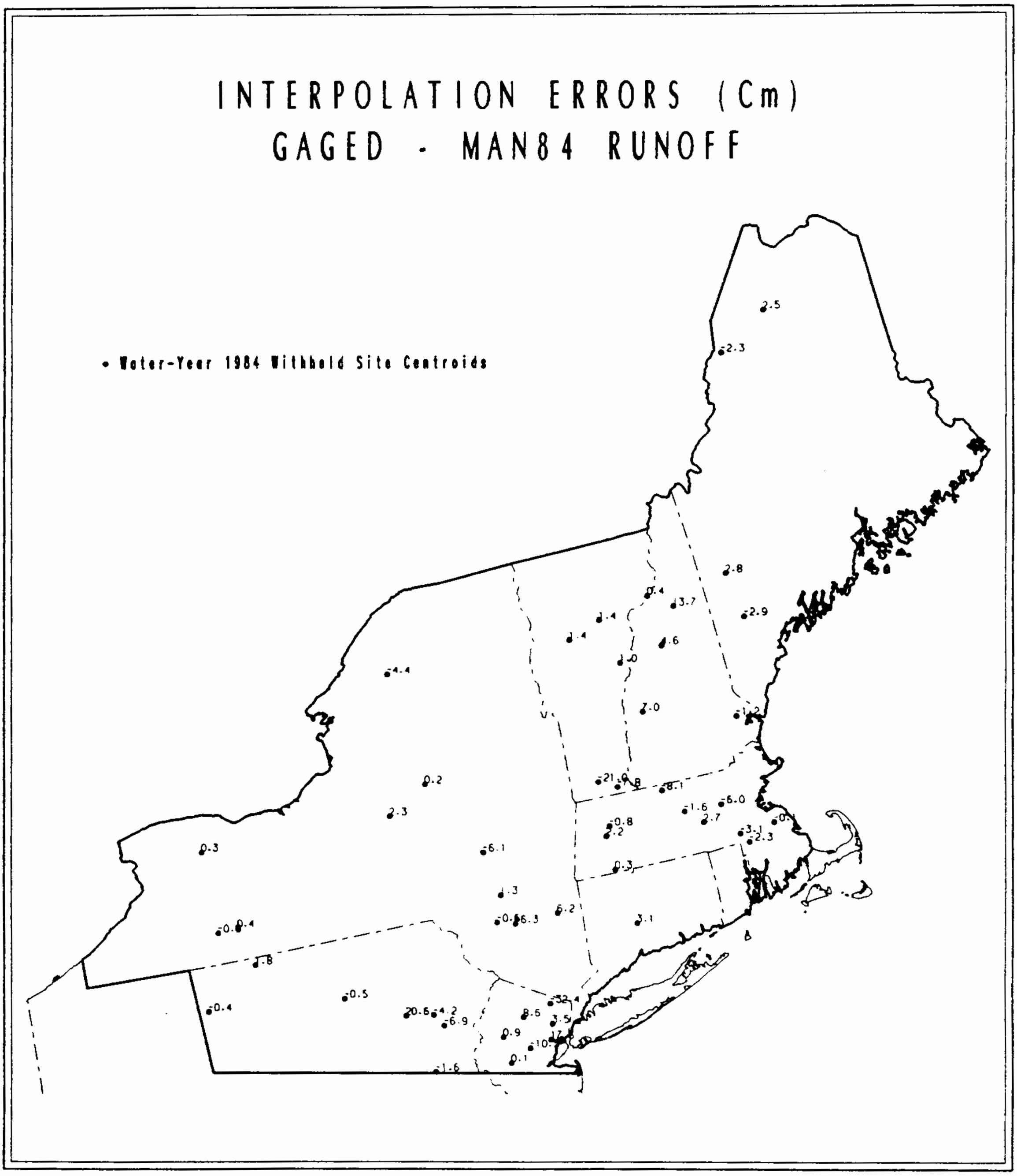


Figure 27. MAN84 Absolute (Cm) Interpolation Errors at the Withheld Sites.

For the manual procedure estimated runoff was interpolated to the withheld sites from the MAN84 map. Differences in the MAN84 interpolated values and the gaged values are the result of the "expert opinion" used by the USGS in creating this map. Most of the errors are due to generalizations in areas of complex hydrology. Several of the high error sites found in the MAN84 error map (Figure 27) correspond to sites with high errors in the automated procedure maps. Thus several areas where the automated procedures had high errors are also not handled well by the manual procedure. One of the sites (1137500 Ammonoosuc River at Bethlehem Junction, NH near Mt. Washington) is an example of the generalization and complex hydrology problem. Estimates from the MAN84 map would overestimate by 13.7 cm the measured runoff-depth at this site while estimates from the automated procedures would be even higher. This is due to the large influence the Mt. Washington precipitation station has on the estimated runoff at this site. This demonstrates one of the weaknesses in the automated procedures in that topographic effects that would temper the influence of the Mt. Washington precipitation site at the Ammonoosuc River gage site are not incorporated into the procedure. A general trend of equivalency or improvement in the results of MNLTET, MNLTRP, REG_R, and MN84RP over GAGE84 was also noted.

Regression Analysis for Bias in Estimated Runoff

A regression analysis was conducted to examine if any bias exists in estimated runoff as compared to actual runoff at the fifty withheld sites. The interpolated runoff was treated as the independent or predictor variable of gaged runoff, the dependent variable. A lack of bias is shown by an intercept that is not significantly different from zero and a slope statistically equivalent to one. The results of the analysis are shown in Table IX. Using a combined hypothesis test that the slope equals one and the intercept equals zero GAGE84, MN84RP, and to a lesser degree REG_R show results consistent with unbiased estimates at the five percent level. The MNLTET and MNLTRP procedures show results consistent with biased estimates with this analysis. As another check on these conclusions scatter plots of interpolated versus gaged runoff (Figure 28-32) were produced. They show the underestimation trend in MNLTRP and overestimation of the MNLTET procedure. No strong bias due to runoff was noted in the plots. This will be further tested with a residual analysis later in this chapter.

TABLE IX

REGRESSION ANALYSIS OF GAGED RUNOFF-DEPTH VERSUS INTERPOLATED RUNOFF-DEPTH[*]

Method	Slope	Standard Error of Slope	Intercept	Standard Error of Intercept	p[**]	R^2
GAGE84	0.887	.094	8.55[***]	8.70[***]	.307	.65
MNLTET	0.551	.085	37.28	8.15	<.001	.47
MNLTRP	0.836	.100	17.99	8.62	.019	.59
REG_R	0.769	.094	20.80	8.47	.057	.58
MN84RP	0.824	.091	15.20	8.26	.165	.63

[*] Interpolated runoff is the predictor
[**] p-value for the combined hypothesis test that the slope equals one and the intercept equals zero.
[***] Cm

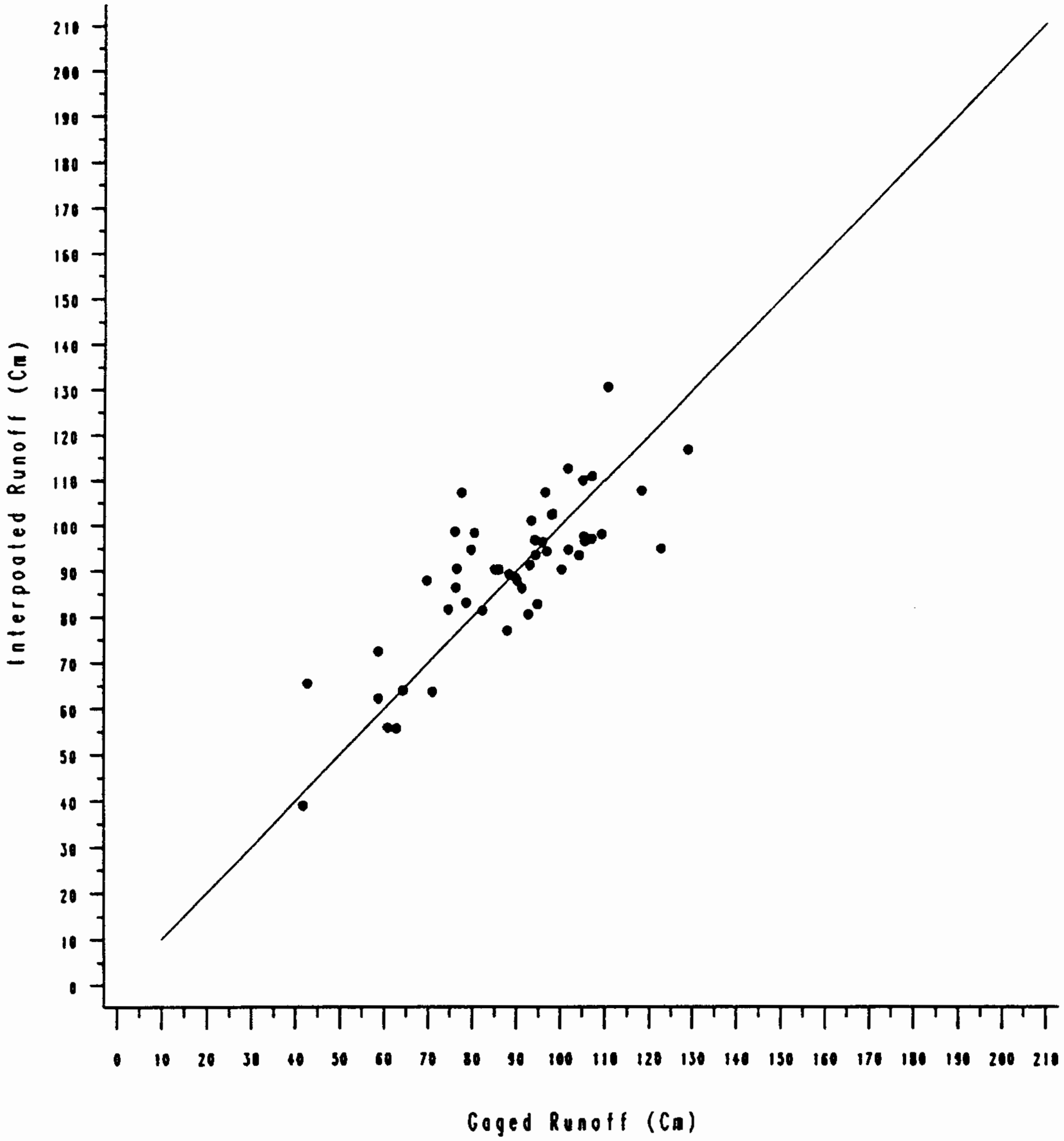


Figure 28. Scatter Plot of GAGE84 Interpolated vs. Gaged Runoff at the 50 Withheld Sites.

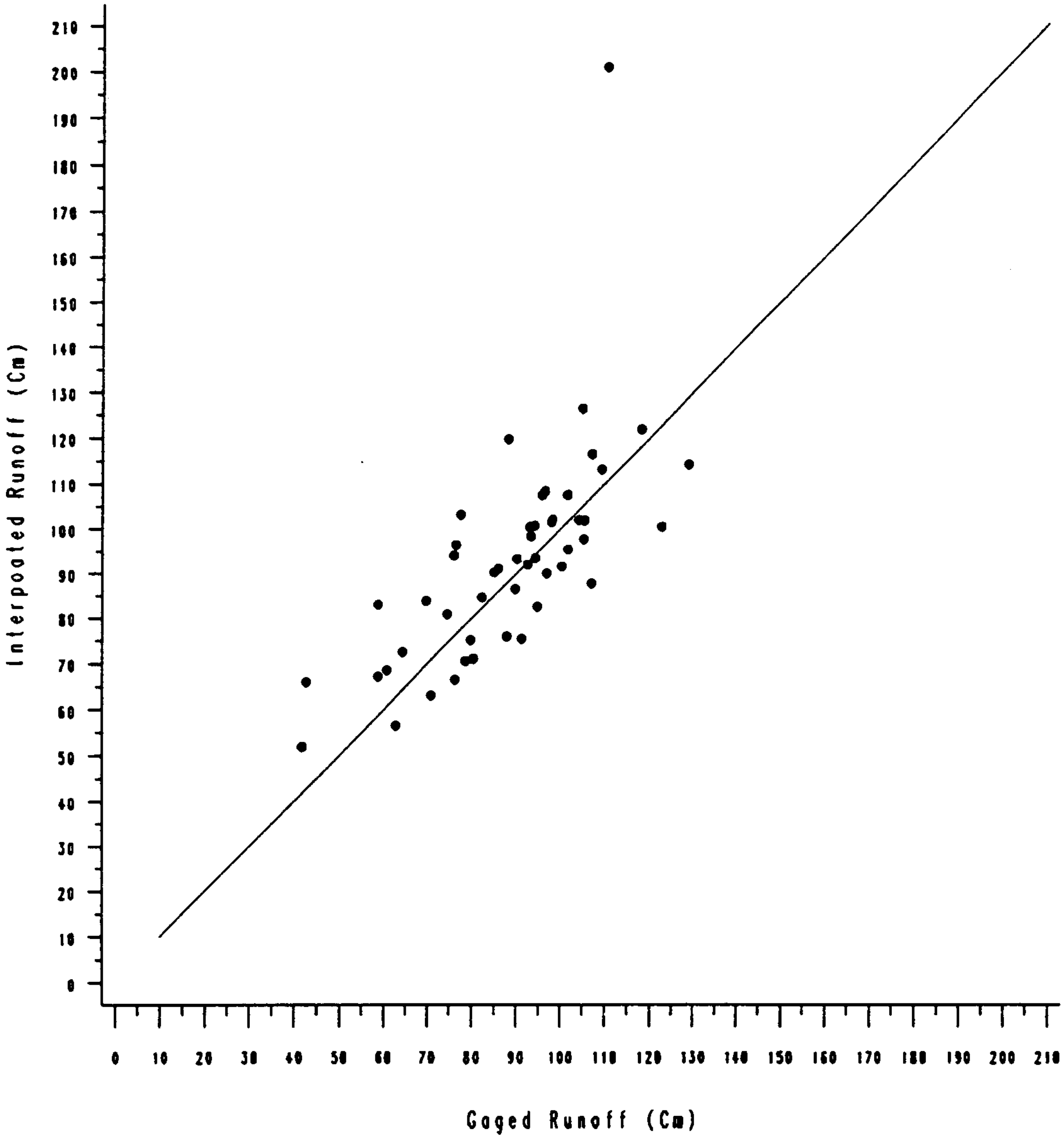


Figure 29. Scatter Plot of MNLTET Interpolated vs. Gaged Runoff at the 50 Withheld Sites.

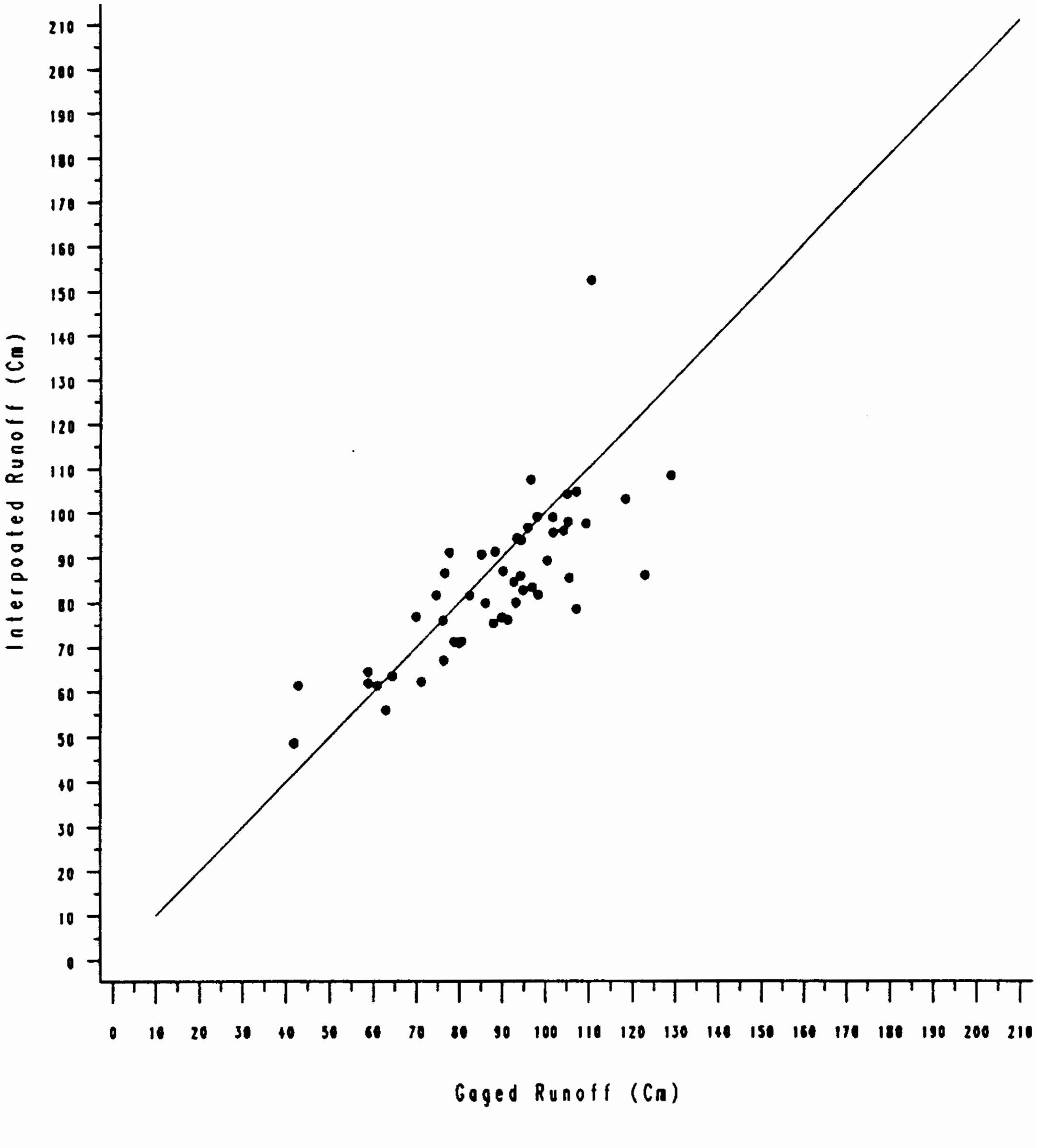


Figure 30. Scatter Plot of MNLTRP Interpolated vs. Gaged Runoff at the 50 Withheld Sites.

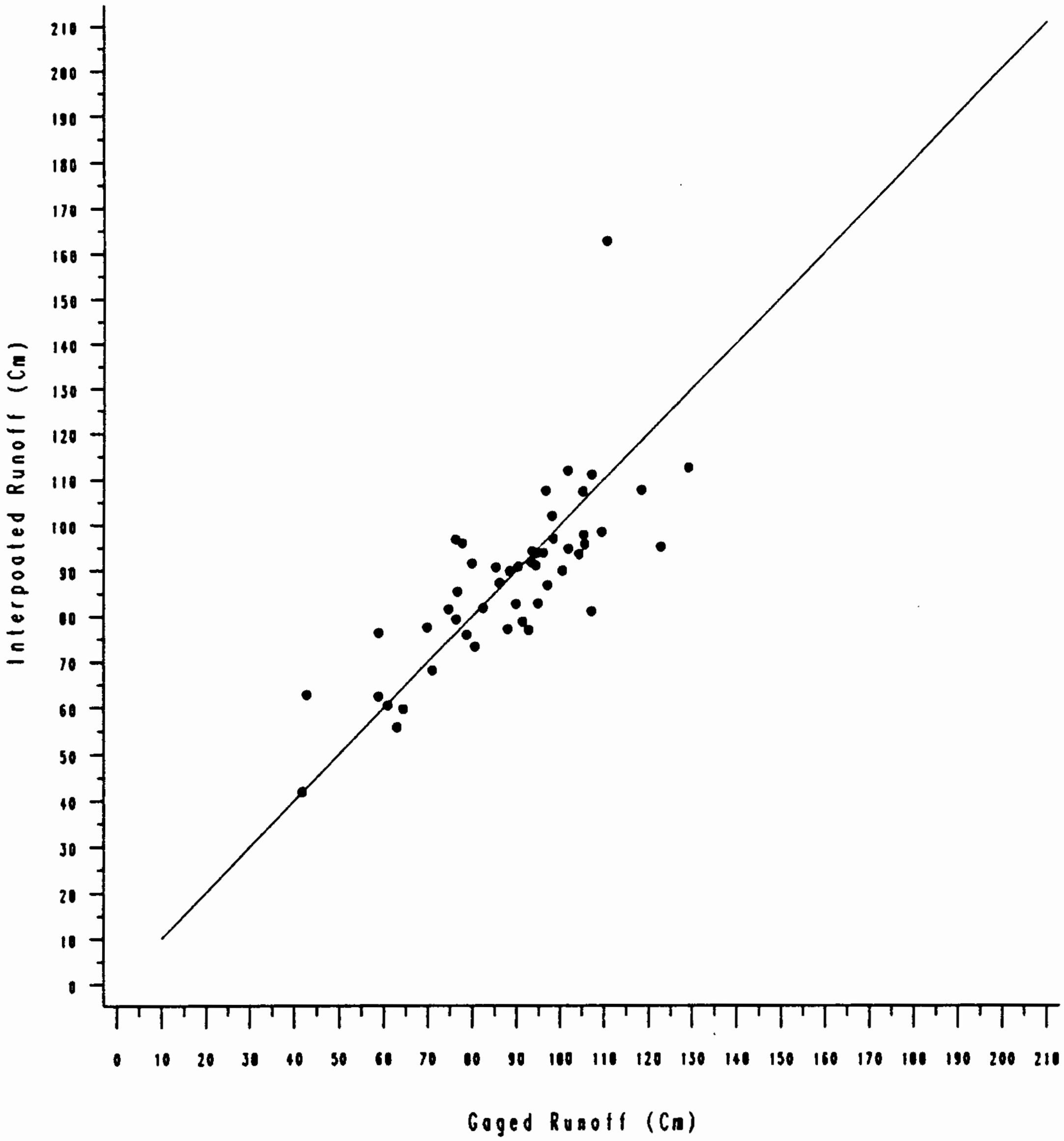


Figure 31. Scatter Plot of REG_R Interpolated vs. Gaged Runoff at the 50 Withheld Sites.

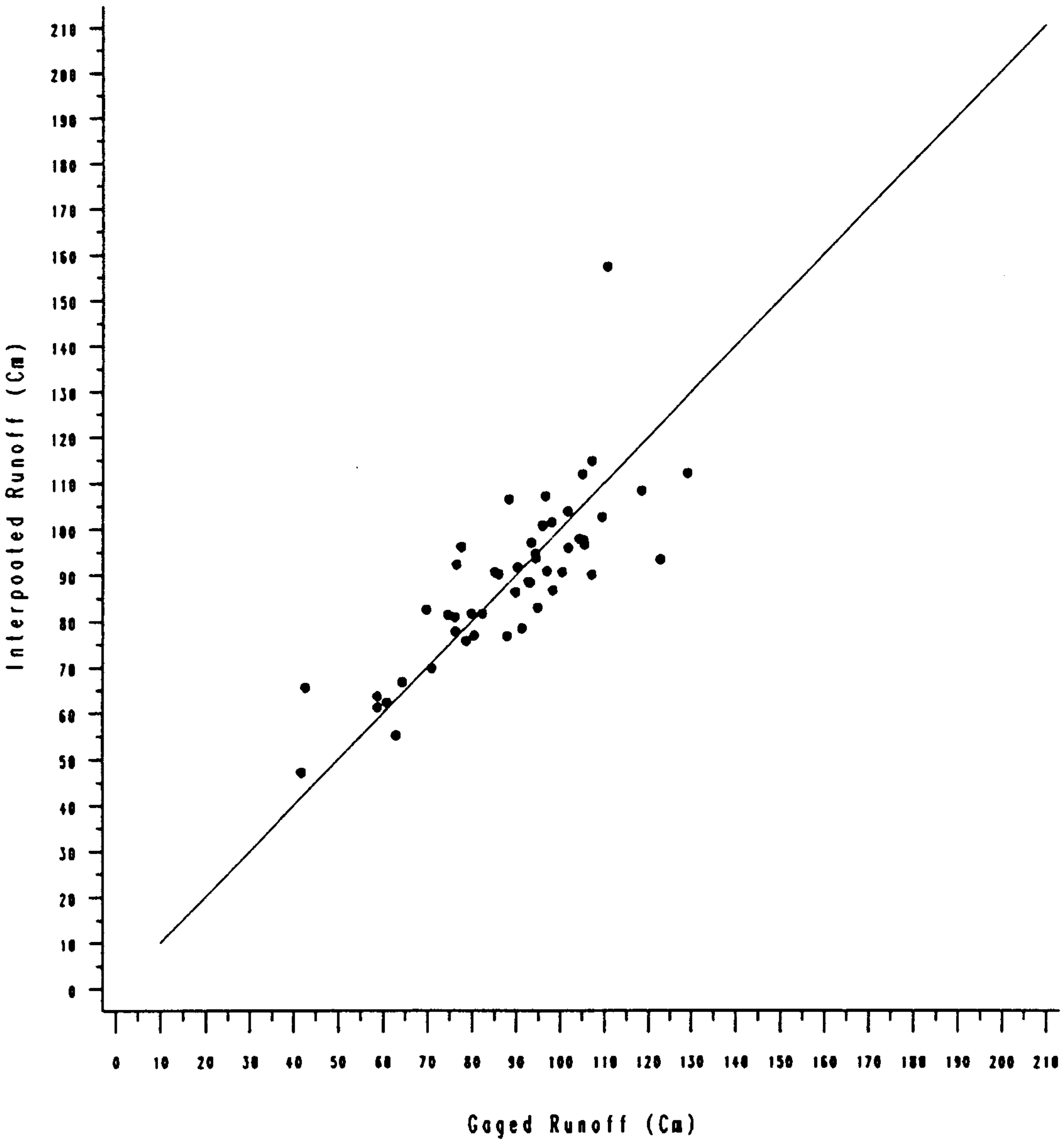


Figure 32. Scatter Plot of MN84RP Interpolated vs. Gaged Runoff at the 50 Withheld Sites.

Biases Due to Elevation, Watershed Area, and Runoff

To examine if there are biases in the runoff estimates or the interpolation errors due to factors such as elevation estimated at the centroid or watershed area a correlation analysis was conducted. Both a Pearson, which assumes a linear relationship between the variables, and a Spearman, which assumes a non-linear relationship, correlation analysis were utilized. Scatterplots were also produced. First, the characteristics of the gaged runoff used in this thesis were examined with the correlation analysis. No correlation was found between runoff-depth and watershed area or elevation from this statistical analysis (Table X). This confirms the findings of Rochelle, *et al.* (1988) who found no relationship between watershed area and runoff-depth for a similar data set from the same area and time period. A visual examination of the scatter plot of runoff vs watershed area shows the variability of runoff-depth to be greater for smaller watersheds thus confirming the findings of Rochelle, *et al.* (1988) and Garbrecht (1991).

Next, interpolation errors were examined for correlations with elevation, watershed area, and runoff. Interpolation errors for all procedures were consistently correlated to gaged runoff except for the Pearson analysis of MNLTET (Table XI and XII). These correlations may be influenced by the non-independence of the interpolation error (estimated - gaged runoff and estimated - gaged / gaged runoff) and the gaged runoff values (Kite, 1989). A likely cause is that due to the regional means and generalizations being used in the procedures, in general a higher than

TABLE X

CORRELATION ANALYSIS OF GAGED RUNOFF-DEPTH VERSUS ELEVATION AND WATERSHED AREA[*]

Pearson		
Elevation	r_p[**]	-0.20
	$P(r_p)$	<.01
Watershed Area	r_p	-0.05
	$P(r_p)$	0.26
Spearman		
Elevation	r_s	-0.27
	$P(r_s)$	<.01
Watershed Area	r_s	-0.20
	$P(r_s)$	<.01

[*] n=441

[**] (r_p=correlation using a Pearson analysis, r_s=correlation using a Spearman analysis, P=the smallest level of significance that would allow the rejection of the null hypothesis (Iman and Conover, 1983).)

average runoff-depth area for the region would be underestimated while a lower than average runoff-depth area for the region will be overestimated (Church, 1991). There is no apparent bias in interpolation errors due to elevation. There is an apparent bias due to watershed size in the MNLTET procedure according to the Spearman analysis but an examination of the scatter plot showed no apparent trend. No other procedure showed any significant bias due to watershed size.

Regional Effects

To examine if any MLRA regional effects on runoff or interpolation errors exist an F-test was conducted. The results are summarized in Table XIII. Regional effects

TABLE XI

CORRELATION ANALYSIS OF ABSOLUTE (Cm) INTERPOLATION ERROR VERSUS GAGED RUNOFF, ELEVATION, AND WATERSHED AREA

		GAGE84	MNLTET	MNLTRP	REG_R	MN84RP
Pearson						
Gaged Runoff	r_p	-0.45	-0.17	-0.44	-0.35	-0.37
	$P(r_p)$	<.01	0.25	<.01	0.01	<.01
Elevation	r_p	-0.12	0.02	-0.06	-0.04	-0.12
	$P(r_p)$	0.39	0.90	0.70	0.79	0.40
Watershed Area	r_p	0.14	-0.20	-0.08	-0.14	-0.09
	$P(r_p)$	0.33	0.17	0.59	0.32	0.52
Spearman						
Gaged Runoff	r_s	-0.44	-0.30	-0.49	-0.45	-0.44
	$P(r_s)$	<.01	0.03	<.01	<.01	<.01
Elevation	r_s	-0.11	-0.10	-0.11	-0.14	-0.18
	$P(r_s)$	0.44	0.50	0.44	0.33	0.20
Watershed Area	r_s	-0.07	-0.32	-0.18	-0.25	-0.20
	$P(r_s)$	0.60	0.02	0.19	0.07	0.17

TABLE XII

CORRELATION ANALYSIS OF PERCENTAGE INTERPOLATION ERROR VERSUS GAGED RUNOFF, ELEVATION, AND WATERSHED AREA

		GAGE84	MNLTET	MNLTRP	REG_R	MN84RP
Pearson						
Gaged Runoff	r_p	-0.47	-0.33	-0.49	-0.42	-0.46
	$P(r_p)$	<.01	0.02	<.01	0.01	<.01
Elevation	r_p	-0.13	-0.03	-0.08	-0.07	-0.15
	$P(r_p)$	0.37	0.81	0.55	0.65	0.30
Watershed Area	r_p	0.10	-0.23	-0.12	-0.18	-0.12
	$P(r_p)$	0.47	0.11	0.39	0.22	0.39
Spearman						
Gaged Runoff	r_s	-0.41	-0.33	-0.44	-0.42	-0.47
	$P(r_s)$	<.01	0.02	<.01	<.01	<.01
Elevation	r_s	-0.13	-0.10	-0.11	-0.14	-0.18
	$P(r_s)$	0.37	0.50	0.44	0.32	0.21
Watershed Area	r_s	-0.08	-0.30	-0.19	-0.26	-0.20
	$P(r_s)$	0.59	0.03	0.18	0.07	0.16

were significant at the one percent level for gaged runoff and at the five percent level for GAGE84 and MN84RP runoff. The significant regional variations in gaged runoff support the use of MLRA's as the regionalization scheme used in MNLTET, MNLTRP, and MN84RP. There were no significant regional effects on interpolation error. REG_R shows no regional differences for runoff. This is probably due to the region-wide nature of the regression formula used.

TABLE XIII

F-TEST OF MLRA EFFECT ON RUNOFF AND INTERPOLATION ERROR VALUES FROM THE FIFTY WITHHELD SITES

	Runoff		Interpolation Error (Cm)		Interpolation Error (%)	
Runoff	F	P(F)	F	P(F)	F	P(F)
Gaged Values	4.50	<.001	----	-----	----	-----
GAGE84	2.65	.016	1.25	.293	1.12	.372
MNLTET	1.12	.372	0.40	.928	1.02	.444
MNLTRP	1.82	.094	1.44	.206	1.65	.135
REG_R	1.63	.140	0.71	.698	0.96	.490
MN84RP	2.71	.014	0.90	.532	0.99	.466

Topographic and Site Density Effects

An analysis was also conducted to determine if interpolation errors were greater in mountainous versus non-mountainous terrain or in areas of low runoff site density. Graczyk, *et al.* (1987) and Krug, *et al.* (1990) state that estimates of runoff-depth from manual procedure maps maybe less accurate in areas of high relief and lower site density although Rochelle, *et al.* (1989) concluded that no such correlation exists due to site density. Generalized mountainous zones were created for this analysis based on areas of higher elevation (greater than 400 meters) and/or steeper slopes (generally greater than 15%). Higher site density zones were based on areas within 13 Km of WY84 runoff sites (Figure 33). The 13 Km distance was based on work by Sopper and Lull (1966, 1970) who found a marked decrease in correlation between runoff and precipitation sites (used to estimate runoff in the automated procedures) in the Northeast greater than this distance. The withheld sites were related to these zones of lesser (*i.e.* mountainous and/or low site density) and greater confidence. Since the lower site density zones are based on WY84 runoff sites none of the withheld sites were in this zone and thus no statistical analysis was possible. Nine of the withheld sites were in the mountainous (lower confidence in estimates) zone. An examination of the means and standard deviations of the two groups (Table XIV) shows higher absolute mean errors and greater standard deviations for the lesser confidence zones. No statistically significant difference was found between the two zones using an F-test (Table XV). The use of this map for gaging relative confidence in the estimates of runoff from these maps, though not proven statistically, may still be a useful tool for applications requiring site specific estimates.

SUMMARY OF FINDINGS

The REG_R and MN84RP procedures were found to have mean errors equivalent to those of the manual procedure as defined by Rochelle, *et al.* (1989) by the uncertainty analysis. No regional biases in the interpolation errors were found which shows equivalence to the results found for the manual procedure by Rochelle,

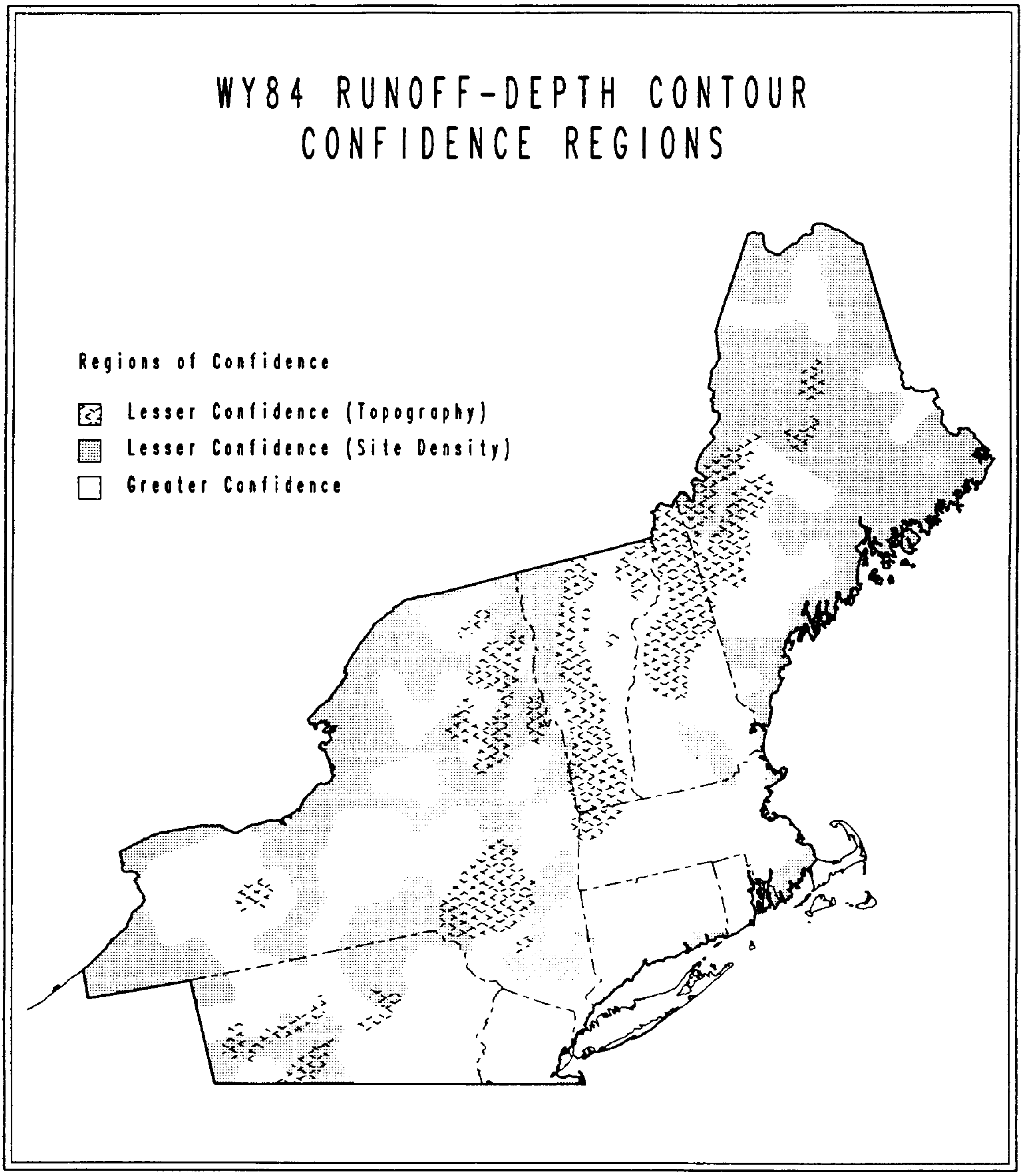


Figure 33. Zones of Lesser and Greater Confidence in Runoff Estimates.

TABLE XIV

DESCRIPTIVE STATISTICS OF INTERPOLATION ERRORS FOR ZONES OF GREATER* AND LESSER** CONFIDENCE

Method	Interpolation Error (Cm) Mean	Interpolation Error (Cm) Standard Deviation	Interpolation Error (%) Mean	Interpolation Error (%) Standard Deviation
> Confidence Zone				
GAGE84	1.41	11.12	3.35	14.76
MNLTET	2.86	11.93	5.37	16.34
MNLTRP	-4.18	10.43	-2.97	12.91
REG_R	-1.08	10.01	0.44	13.00
MN84RP	0.34	9.88	2.19	12.95
< Confidence Zone				
GAGE84	2.47	12.92	2.71	14.55
MNLTET	11.72	32.15	10.81	30.04
MNLTRP	-4.28	19.63	-4.92	18.28
REG_R	2.23	22.44	2.14	21.92
MN84RP	0.52	19.23	-0.20	18.16

*Non-Mountainous (n=41)
**Mountainous (n=9)

TABLE XV

F-TEST OF MEAN INTERPOLATION ERROR VALUES FOR ZONES OF GREATER* AND LESSER** CONFIDENCE

Method	Interpolation Error (Cm) F	Interpolation Error (Cm) P(F)	Interpolation Error (%) F	Interpolation Error (%) P(F)
GAGE84	0.06	.804	0.01	.907
MNLTET	1.99	.165	0.59	.448
MNLTRP	0.00	.983	0.15	.705
REG_R	0.48	.490	0.10	.757
MN84RP	0.00	.967	0.22	.644

*Non-Mountainous (n=41)
**Mountainous (n=9)

et al. (1989). Bias in interpolation errors when compared to gaged runoff was found for all methods. The non-independence of the variables and/or the regional generalizations in the procedures used are possible explanations. Since this bias was not tested for with the manual procedure it cannot be assumed that this is a weakness found only in the automated procedures. No biases in interpolation errors were found due to elevation or watershed area, other than a statistically significant bias for watershed area for the MNLTET procedure which was not supported by a visual inspection of the related scatter plot. A regression analysis between actual and estimated runoff showed that GAGE84, MN84RP (at the five percent level) and REG_R (at the one percent level) showed results consistent with unbiased estimates. No statistically significant bias was found for interpolation errors in mountainous terrain.

CHAPTER V

SUMMARY AND FUTURE AREAS OF RESEARCH

SUMMARY

This thesis hypothesized that a simple automated procedure can produce as accurate a water-year runoff-depth contour map as that produced by the manual procedure currently used by the U.S. Geological Survey (USGS). Five (GAGE84, MNLTET, MNLTRP, REG_R, and MN84RP) maps for WY84 derived from automated procedures were tested with an uncertainty analysis to see if actual runoff values matched those predicted from the contour maps produced by the procedures. Two of the procedures, REG_R and MN84RP with mean percentage errors of -0.74 and -1.76% respectively, were found to be equivalent to the mean percentage error noted for the manual method, 0.9% determined by Rochelle, *et al.* (1989). No biases in interpolation error by Major Land Resource Area (MLRA) were found and no biases were found in predicted runoff due to elevation or watershed size. This lack of bias was also noted for the manual procedure (Rochelle, *et al.*, 1988,1989). Bias in the interpolation error due to runoff-depth was found for the automated procedures with larger interpolation errors occurring at watersheds with greater runoff-depth. It is not known whether this bias exists in the manual procedure maps.

The simplifying assumption that R/P remains constant over time was shown to be inappropriate by the results of this thesis. The success of the MN84RP method indicates that regionalization of R/P values to predict runoff at precipitation stations is appropriate if data for the given water-year is used and a mean regional accuracy is required. The assumption that ET remains constant over time was shown to be statistically appropriate by the results of the uncertainty analysis although the accuracy of the results obtained was lower than the other methods examined. The use of long-term data was shown to be useful by the positive results of the REG_R procedure, but is not required as evidenced by the results of the MN84RP procedure.

The two methodologies, REG_R and MN84RP, are put forth as acceptable methods for producing runoff-depth contour maps for projects requiring a mean regional accuracy of about 1%. Caution should be used if estimates of runoff for individual sites are needed from one of these maps. As with all estimations from runoff-depth contour maps, large differences from actual values may occur due to local conditions. Individual site estimation errors of 15% or greater are not to be unexpected with maps generated by the automated procedures. Until better methodologies are perfected these two procedures should provide an adequate, inexpensive means of producing a water-year specific map for wetter than normal water-years in the Northeast.

FUTURE AREAS OF RESEARCH

The procedures tested in this thesis are not intended to be the final solution to the problem of automating the production of runoff-depth contour maps. Even in their present form there is a need for further testing of the automated procedures on water-years with below normal and normal precipitation as well as for other regions. Further refinement of the REG_R procedure with the use of regression formulas created for MLRA or MLRA groupings would also be worth investigation.

Research into the use of artificial intelligence for producing runoff-depth maps is an area that might also yield worthwhile results. The incorporation of the decision making processes used by the expert hydrologists at the USGS into an automated procedure could greatly improve the results of automated mapping of runoff-depth.

With further research into automated methods the time-consuming and expensive manual procedure in use by the USGS can be replaced. The advantages of lower costs, reproduceability, and standardization of methods, especially in regards to known accuracy, will make the time and cost involved in researching these new methods worthwhile.

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APPENDIX A

WATER-YEAR 1984 USGS GAGING STATIONS IN THE NORTHEAST UNITED STATES

ID	NAME	WATERSHED AREA KM^2	EST ELEV (M)	RUNOFF (CM)
1021200	DENNYS RIVER AT DENNYSVILLE ME	240.6	57	97.68
1013500	FISH RIVER NEAR FORT KENT ME	2261.0	195	82.67
1015800	AROOSTOOK RIVER NEAR MASARDIS ME	2310.2	279	76.96
1030500	MATTAWAMKEAG RIVER NEAR MATTAWAMKEAG ME	3672.6	185	97.71
1019000	GRAND LAKE STREAM AT GRAND LAKE STREAM ME	587.9	92	78.43
1010500	ST. JOHN RIVER AT DICKEY ME	6941.2	360	88.41
1011000	ALLAGASH RIVER NEAR ALLAGASH ME	3183.1	404	78.61
1010000	ST. JOHN RIVER AT NINEMILE BRIDGE ME	3473.1	396	91.28
1031500	PISCATAQUIS RIVER NEAR DOVER-FOXCROFT ME	771.8	276	111.27
1049000	SEBASTICOOK RIVER NEAR PITTSFIELD ME	1481.4	105	93.49
1038000	SHEEPSCOT RIVER AT NORTH WHITEFIELD ME	375.5	84	101.60
1049500	COBBOSSEECONTEE STREAM AT GARDINER ME	562.0	57	114.96
1047000	CARRABASSETT RIVER NEAR NORTH ANSON ME	914.2	416	108.68
1055000	SWIFT RIVER NEAR ROXBURY ME	250.9	393	96.13
1057000	LITTLE ANDROSCOGGIN RIVER NEAR SOUTH PARIS ME	196.3	272	95.58
1055500	NEZINSCOT RIVER AT TURNER CENTER ME	437.7	200	98.39
1064000	PRESUMPSCOT RIVER AT OUTLET OF SEBAGO LAKE ME	1142.1	142	85.36
1060000	ROYAL RIVER AT YARMOUTH ME	365.1	57	117.44
1069500	MOUSAM RIVER NEAR WEST KENNEBUNK ME	256.4	159	111.86
1128500	CONNECTICUT R AT FIRST CONN LK NR PITTSBURG NH	214.9	560	81.48
1127880	BIG BROOK NEAR PITTSBURG NH	16.4	588	96.01
1129200	CONNECTICUT R BL INDIAN STREAM NR PITTSBURG NH	657.8	579	78.10
1130000	UPPER AMMONOOSUC RIVER NEAR GROVETON NH	600.8	346	88.77
1054200	WILD RIVER AT GILEAD ME	180.2	573	128.39
1064300	ELLIS RIVER NEAR JACKSON NH	28.2	827	146.86
1137500	AMMONOOSUC RIVER AT BETHLEHEM JUNCTION NH	226.8	531	110.66
1064400	LUCY BROOK NEAR NORTH CONWAY NH	11.9	390	113.25
1134500	MOOSE RIVER AT VICTORY VT	194.7	453	85.34
4296500	CLYDE RIVER AT NEWPORT VT	367.7	480	72.89
1065000	OSSIPEE RIVER AT EFFINGHAM FALLS NH	854.7	575	108.10
1075800	STEVENS BROOK NEAR WENTWORTH NH	7.6	281	81.43
1077000	SQUAM RIVER AT ASHLAND NH	149.1	202	89.83
1072100	SALMON FALLS RIVER AT MILTON NH	279.7	192	98.06

ID	NAME	WATERSHED AREA KM^2	EST ELEV (M)	RUNOFF (CM)
1078000	SMITH RIVER NEAR BRISTOL NH	222.2	434	86.05
1087000	BLACKWATER RIVER NEAR WEBSTER NH	334.1	311	88.26
1073600	DUDLEY BROOK NEAR EXETER NH	12.8	30	81.91
1073500	LAMPREY RIVER NEAR NEWMARKET NH	473.9	93	83.13
1073000	OYSTER RIVER NEAR DURHAM NH	31.3	58	89.81
1093800	STONY BROOK TRIBUTARY NEAR TEMPLE NH	9.3	471	104.47
4280000	POULTNEY RIVER BELOW FAIR HAVEN VT	484.3	176	78.96
1334000	WALLOOMSAC RIVER NEAR NORTH BENNINGTON VT	287.4	327	90.75
1334500	HOOSIC RIVER NEAR EAGLE BRIDGE NY	1320.9	328	89.02
4296000	BLACK RIVER AT COVENTRY VT	315.9	354	64.18
4293000	MISSISQUOI RIVER NEAR NORTH TROY VT	339.2	264	82.44
4292000	LAMOILLE RIVER AT JOHNSON VT	802.9	356	75.56
4289000	LITTLE RIVER NEAR WATERBURY VT	287.4	322	93.24
4285500	NORTH BRANCH WINOOSKI RIVER AT WRIGHTSVILLE VT	179.2	371	87.75
4286000	WINOOSKI RIVER AT MONTPELIER VT	1028.2	352	74.47
1139000	WELLS RIVER AT WELLS RIVER VT	254.8	344	78.89
4288000	MAD RIVER NEAR MORETOWN VT	360.0	505	87.85
4287000	DOG RIVER AT NORTHFIELD FALLS VT	197.0	376	76.17
1139800	EAST ORANGE BRANCH AT EAST ORANGE VT	23.1	545	87.88
1142500	AYERS BROOK AT RANDOLPH VT	78.9	248	82.57
1141500	OMPOMPANOOSUC RIVER AT UNION VILLAGE VT	336.7	403	76.17
1141800	MINK BROOK NEAR ETNA NH	11.9	399	90.01
1151500	OTTAUQUECHEE RIVER AT NORTH HARTLAND VT	572.3	407	85.69
4282000	OTTER CREEK AT CENTER RUTLAND VT	795.1	370	77.87
1152500	SUGAR RIVER AT WEST CLAREMONT NH	696.7	370	79.78
1085800	WEST BRANCH WARNER RIVER NEAR BRADFORD NH	14.8	454	97.81
1153500	WILLIAMS RIVER AT BROCKWAYS MILLS VT	266.7	400	86.08
1155500	WEST RIVER AT JAMAICA VT	463.6	398	101.39
1156000	WEST RIVER AT NEWFANE VT	797.7	387	96.77
1158600	OTTER BROOK BELOW OTTER BROOK DAM NR KEENE NH	122.2	398	87.70
1158000	ASHUELOT RIVER BL SURRY MT DAM NR KEENE NH	261.5	381	86.76
1083000	NUBANUSIT BROOK NEAR PETERBOROUGH NH	121.4	374	97.10
1164000	MILLERS RIVER AT SOUTH ROYALSTON MA	489.5	328	93.47

ID	NAME	WATERSHED AREA KM^2	EST ELEV (M)	RUNOFF (CM)
1162500	PRIEST BROOK NEAR WINCHENDON MA	50.2	338	85.19
1165000	EAST BRANCH TULLY RIVER NEAR ATHOL MA	130.7	329	96.34
1170100	GREEN RIVER NEAR COLRAIN MA	107.2	463	105.00
1169000	NORTH RIVER AT SHATTUCKVILLE MA	230.5	454	115.92
1168151	DEERFIELD RIVER NEAR ROWE MA	657.8	622	118.31
1205700	EAST BRANCH NAUGATUCK RIVER AT TORRINGTON CT	35.2	327	100.20
1199050	SALMONC K AT LIME ROCK CT	76.1	401	82.98
1186500	STILL R AT ROBERTSVILLE CT	220.1	371	96.18
1208420	HOP BK NR NAUGATUCK CT	42.2	156	94.81
1208990	SAUGATUCK R NR REDDING CT	54.3	156	122.88
1208950	SASCO BK NR SOUTHPORT CT	19.1	56	103.78
1188000	BURLINGTON BK NR BURLINGTON CT	10.6	253	102.66
1196500	QUINNIPIAC R AT WALLINGFORD CT	297.8	64	107.11
1196620	MILL R NR HAMDEN CT	63.4	61	119.83
1127500	YANTIC R AT YANTIC CT	231.2	131	106.24
1193500	SALMON R NR EAST HAMPTON CT	259.0	131	98.67
1123000	LITTLE R NR. HANOVER CT	77.7	149	99.13
1192500	HOCKANUM R NR EAST HARTFORD CT	190.1	151	82.27
1121000	MOUNT HOPE R NR WARRENVILLE CT	74.0	184	89.38
1101000	PARKER RIVER AT BYFIELD MA	55.1	28	104.97
1111300	NIPMUC RIVER NEAR HARRISVILLE RI	41.4	142	96.82
1111500	BRANCH RIVER AT FORESTDALE RI	236.2	132	98.72
1114500	WOONASQUATUCKET RIVER AT CENTERDALE RI	99.1	80	107.21
1114000	MOSHASSUCK RIVER AT PROVIDENCE RI	59.8	59	87.37
1117800	WOOD RIVER NEAR ARCADIA RI	91.1	90	108.78
1117468	BEAVER RIVER NEAR USQUEPAUG RI	22.9	100	117.47
1117500	PAWCATUCK RIVER AT WOOD RIVER JUNCTION RI	259.0	39	107.31
1333000	GREEN RIVER AT WILLIAMSTOWN MA	110.3	426	82.60
1332500	HOOSIC RIVER NEAR WILLIAMSTOWN MA	326.3	298	93.37
1181000	WEST BRANCH WESTFIELD RIVER AT HUNTINGTON MA	243.4	390	104.97
1197500	HOUSATONIC RIVER NEAR GREAT BARRINGTON MA	730.3	376	88.08
1185500	WEST BRANCH FARMINGTON RIVER NEAR NEW BOSTON MA	237.5	419	100.07
1187300	HUBBARD RIVER NR. WEST HARTLAND CT	51.5	377	95.88

ID	NAME	WATERSHED AREA KM^2	EST ELEV (M)	RUNOFF (CM)
1180500	MIDDLE B WESTFIELD RIVER AT GOSS HEIGHTS MA	136.4	407	104.08
1179500	WESTFIELD RIVER AT KNIGHTVILLE MA	416.9	396	109.29
1169900	SOUTH RIVER NEAR CONWAY MA	62.4	319	109.09
1174900	CADWELL CREEK NEAR BELCHERTOWN MA	6.6	270	94.58
1174500	EAST BRANCH SWIFT RIVER NEAR HARDWICK MA	113.1	276	85.26
1162000	MILLERS RIVER NEAR WINCHENDON MA	211.8	326	96.59
1123360	QUINEBAUG R BL E BRIMFIELD DAM AT FISKDALE MA	174.5	251	91.10
1163200	OTTER RIVER AT OTTER RIVER MA	88.3	317	91.05
1175670	SEVENMILE RIVER NEAR SPENCER MA	22.4	260	87.85
1124350	FRENCH RIVER BELOW DAM AT HODGES VILLAGE MA	80.8	222	90.77
1110000	QUINSIGAMOND RIVER AT NORTH GRAFTON MA	66.3	134	85.97
1111200	WEST RIVER BELOW WEST HILL DAM NR UXBRIDGE MA	72.2	111	101.90
1097000	ASSABET RIVER AT MAYNARD MA	300.4	94	88.03
1097300	NASHOBA BROOK NEAR ACTON MA	33.1	68	78.71
1105585	TOWN BROOK AT QUINCY MA	10.9	32	127.53
1105600	OLD SWAMP RIVER NEAR SOUTH WEYMOUTH MA	11.6	33	110.41
1105730	INDIAN HEAD RIVER AT HANOVER MA	78.2	26	101.57
4231000	BLACK CREEK AT CHURCHVILLE NY	336.7	214	41.65
4216500	LITTLE TONAWANDA CREEK AT LINDEN NY	57.2	434	64.31
4230500	OATKA CREEK AT GARBUTT NY	518.0	307	52.62
4230380	OATKA CREEK AT WARSAW NY	101.2	444	56.13
4215500	CAZENOVIA CREEK AT EBENEZER NY	349.6	422	79.47
4235250	FLINT CREEK AT PHELPS NY	264.1	283	33.75
1528000	FIVEMILE CREEK NEAR KANONA NY	173.0	429	49.83
1521500	CANISTEO RIVER AT ARKPORT NY	79.2	534	58.75
1523500	CANACADEA CR NR HORNELL NY	149.9	530	60.78
4221000	GENESEE RIVER AT WELLSVILLE NY	745.9	657	62.53
4232100	STERLING CREEK AT STERLING NY	114.9	128	59.13
4240120	LEY CREEK AT PARK STREET SYRACUSE NY	77.4	121	54.00
4245200	BUTTERNUT CREEK NEAR JAMESVILLE NY	83.3	374	54.00
1508803	W BR TIOUGHNIOGA R AT HOMER NY	185.1	376	62.25
4235500	OWASCO OUTLET NEAR AUBURN NY	533.5	258	56.43
4233000	CAYUGA INLET NEAR ITHACA NY	91.1	292	56.46

ID	NAME	WATERSHED AREA KM^2	EST ELEV (M)	RUNOFF (CM)
1530500	NEWTOWNC REEK AT ELMIRA NY	200.7	362	61.44
4262500	WEST BRANCH OSWEGATCHIE RIVER NEAR HARRISVILLE	631.9	399	85.97
4266500	RAQUETTE RIVER AT PIERCEFIELD NY	1867.3	547	75.66
1312000	HUDSON RIVER NEAR NEWCOMB NY	497.2	540	83.03
4270200	LITTLE SALMON RIVER AT BOMBAY NY	238.7	211	47.14
4273500	SARANAC RIVER AT PLATTSBURGH NY	1574.7	471	58.95
4270510	CHATEAUGAY RIVER BELOW CHATEAUGAY NY	391.0	500	61.69
4275000	E BR AUSABLE R AT AUSABLE FORKS NY	512.8	303	74.93
4250750	SANDY CREEK NEAR ADAMS NY	331.5	371	79.78
4256000	INDEPENDANCE RIVER AT DONNATSBURG NY	229.7	491	87.12
4242500	EAST BRANCH FISH CREEK AT TABERG NY	486.9	409	106.07
4252500	BLACK RIVER NEAR BOONVILLE NY	787.3	503	92.50
4243500	ONEIDA CREEK AT ONEIDA NY	292.6	207	58.62
4257000	BEAVER R BELOW STILLWATER DAM NEAR BEAVER R NY	441.8	546	93.85
1315000	INDIAN RIVER NEAR INDIAN LAKE NY	341.8	515	97.76
1321000	SACANDAGA RIVER NEAR HOPE NY	1271.6	740	93.75
1330500	KAYDEROSSERAS CREEK NR WEST MILTON NY	233.1	211	71.67
4245000	LIMESTONE CREEK AT FAYETTEVILLE NY	221.4	366	60.52
1510000	OTSELIC RIVER AT CINCINNATUS NY	380.7	475	66.64
1502000	BUTTERNUT CREEK AT MORRIS NY	154.6	473	58.95
1500000	OULEOUT CREEK AT EAST SIDNEY NY	266.7	526	62.30
1349000	OTSQUAGO CREEK AT FORT PLAIN NY	153.3	206	52.34
1496500	OAKS CREEK AT INDEX NY	264.1	422	55.14
1350200	WEST KILL AT NORTH BLENHEIM NY	115.5	508	62.81
1350140	MINE KILL NEAR NORTH BLENHEIM NY	42.2	550	57.35
1350120	PLATTER KILL AT GILBOA NY	28.7	594	52.52
1415000	TREMPER KILL NEAR ANDES NY	85.9	546	69.82
1413500	EAST BR DELAWARE R AT MARGARETVILLE NY	423.2	776	78.53
1350000	SCHOHARIE C AT PRATTSVILLE NY	611.2	589	90.93
1414500	MILL BROOK NEAR DUNRAVEN NY	65.2	705	79.27
1359750	MOORDENER KILL AT CASTLETON-ON-HUDSON NY	84.4	155	63.50
1333500	LITTLE HOOSIC RIVER AT PETERSBURG NY	145.2	359	81.17
1435000	NEVERSINK RIVER NEAR CLARYVILLE NY	172.4	807	107.74

ID	NAME	WATERSHED AREA KM^2	EST ELEV (M)	RUNOFF (CM)
1365000	RONDOUT CREEK NEAR LOWES CORNERS NY	99.7	618	110.23
1365500	CHESTNUT CREEK AT GRAHAMSVILLE NY	54.1	436	76.09
1433500	MONGAUP RIVER NEAR MONGAUP NY	518.0	363	79.34
1387500	RAMAPO RIVER NEAR MAHWAH NJ	305.6	263	113.46
1377000	HACKENSACK RIVER AT RIVERVALE NJ	150.2	87	85.06
1200000	TENMILE R NR GAYLORDSVILLE CT	525.7	199	78.35
1376800	HACKENSACK RIVER AT WEST NYACK NY	76.1	50	86.96
1301000	MAMARONECK RIVER AT MAMARONECK NY	60.6	51	103.35
1300000	BLIND BROOK AT RYE NY	23.8	39	105.38
1300500	BEAVER SWAMP BROOK AT MAMARONECK NY	12.1	12	84.25
1301500	HUTCHINSON RIVER AT PELHAM NY	14.9	31	73.68
1383500	WANAQUE R AT AWOSTING NJ	70.1	297	133.68
1542810	WALDY RUN NEAR EMPORIUM PA	13.5	532	82.29
1543000	DRIFTWOOD BR SINNEMAHONING CR STERLING RUN PA	704.4	502	84.98
1544000	F FORK SINNEMAHONING CR NR SINNEMAHONING PA	634.5	594	74.65
1520000	COWANESQUE RIVER NR. LAWRENCEVILLE PA	771.8	560	57.65
1516350	TIOGA RIVER NEAR MANSFIELD PA	396.2	580	70.81
1548500	PINE CREEK AT CEDAR RUN PA	1564.3	543	70.94
1544500	KETTLE CREEK AT CROSS FORK PA	352.2	569	75.33
1545600	YOUNG WOMANS CREEK NEAR RENOVO PA	119.6	546	70.12
1547950	BEECH CREEK AT MONUMENT PA	393.6	393	74.90
1547700	MARSH CREEK AT BLANCHARD PA	114.2	367	72.05
1516500	COREY CREEK NEAR MAINESBURG PA	31.5	487	61.92
1532000	TOWANDA CREEK NEAR MONROETOWN PA	556.8	339	78.94
1550000	LYCOMING CREEK NEAR TROUT RUN PA	448.0	445	87.55
1552000	LOYALSOCK CR AT LOYALSOCKVILLE PA	1147.3	447	85.03
1552500	MUNCY CREEK NEAR SONESTOWN PA	61.6	499	96.39
1539000	FISHING CREEK NEAR BLOOMSBURG PA	709.6	351	80.21
1554500	SHAMOKINC R NR SHAMOKIN (SHAMOKIN A) PA	140.3	318	73.20
1534300	LACKAWANNA R NR FOREST CITY (FOREST CITY A) PA	100.4	585	78.96
1534000	TUNKHANNOCK CREEK NEAR TUNKHANNOCK PA	991.9	359	60.27
1429000	W BR LACKAWAXEN RIVER AT PROMPTON PA	154.6	442	80.89
1429500	DYBERRY CREEK NEAR HONESDALE PA	167.3	419	82.24

ID	NAME	WATERSHED AREA KM^2	EST ELEV (M)	RUNOFF (CM)
1534500	LACKAWANNA RIVER AT ARCHBALD PA	279.7	325	84.65
1432000	WALLENPAUPACK CREEK AT WILSONVILLE PA	590.5	404	81.25
1537500	SOLOMONC REEK AT WILKES-BARRE PA	40.6	223	42.62
1447500	LEHIGH RIVER AT STODDARTSVILLE PA	237.5	557	95.58
1440400	BRODHEAD CREEK NEAR ANALOMINK PA	170.6	332	95.27
1447720	TOBYHANNA CREEK NEAR BLAKESLEE PA	305.6	545	103.22
1538000	WAPWALLOPENC REEK NEAR WAPWALLOPEN PA	113.4	408	67.66
1448500	DILLDOWNC REEK NEAR LONG POND PA	6.1	532	89.50
1447680	TUNKHANNOCK CREEK NEAR LONG POND PA	46.6	577	122.68
1442500	BRODHEAD CREEK AT MINISINK HILLS PA	670.8	343	110.56
1449360	POHOPOCO CREEK AT KRESGEVILLE PA	129.2	327	90.57
1451800	JORDANC REEK NEAR SCHNECKSVILLE PA	137.2	193	93.09
1452000	JORDANC REEK AT ALLENTOWN PA	196.3	145	92.40
1452500	MONOCACY CREEK AT BETHLEHEM PA	115.2	117	69.54
1377500	PASCACK BROOK AT WESTWOOD NJ	76.6	24	99.31
1390500	SADDLE R AT RIDGEWOOD NJ	55.9	75	93.75
1391000	HOHOKUS BROOK AT HO-HO-KUS NJ	42.4	101	128.95
1443500	PAULINS KILL AT BLAIRSTOWN NJ	326.3	193	84.32
1440000	FLAT BROOK NEAR FLATBROOKVILLE NJ	165.7	175	81.94
1393450	ELIZABETH RIVER AT URSINO LAKE AT ELIZABETH NJ	43.7	24	91.46
1379000	PASSAIC RIVER NEAR MILLINGTON NJ	143.4	115	101.52
1381500	WHIPPANY RIVER AT MORRISTOWN NJ	76.1	123	115.59
1399500	LAMINGTON (BLACK) R NR POTTERSVILLE NJ	84.9	250	102.03
1398500	NORTH BRANCH RARITAN RIVER NEAR FAR HILLS NJ	67.8	147	108.25
1400000	NORTH BRANCH RARITAN RIVER NEAR RARITAN NJ	492.1	143	109.85
1396500	SOUTH BRANCH RARITAN RIVER NEAR HIGH BRIDGE NJ	169.1	188	107.79
1445500	PEQUEST RIVER AT PEQUEST NJ	274.5	177	80.72
1396800	SPRUCE RUN AT CLINTON NJ	106.9	85	78.20
1398000	NESHANIC R AT REAVILLE NJ	66.5	59	89.40
1405000	LAWRENCE BROOK AT FARRINGTON DAM NJ	89.0	29	58.67
1010070	BIG BLACK RIVER NEAR DEPOT MTN ME	442.8	339	88.36
1012525	BISHOP MOUNTAIN BROOK NR BISHOP MTN ME SITE 14	2.6	271	76.63
1012520	BALD MOUNTAIN BROOK NR BALD MOUNTAIN ME SITE 2	4.3	291	77.97

ID	NAME	WATERSHED AREA KM^2	EST ELEV (M)	RUNOFF (CM)
1030000	PENOBSCOT RIVER NEAR MATTAWAMKEAG ME	8692.0	320	81.81
1034500	PENOBSCOT RIVER AT WEST ENFIELD ME	17277.8	333	90.88
1047730	WILSON STREAM AT EAST WILTON ME	118.6	213	97.94
1049265	KENNEBEC RIVER AT NORTH SIDNEY ME	13993.7	367	87.22
1022260	PLEASANT RIVER NEAR EPPING ME (SW SITE 13)	156.9	102	110.46
1049130	JOHNSON BROOK AT SOUTH ALBION ME	7.5	83	96.54
1049550	TOGUS STREAM AT TOGUS ME	61.3	69	99.56
1049373	MILL STREAM AT WINTHROP ME	84.6	84	101.93
1059000	ANDROSCOGGIN RIVER NEAR AUBURN ME	8451.1	387	93.34
1017000	AROOSTOOK RIVER AT WASHBURN ME	4283.8	238	80.28
1018500	ST. CROIX RIVER AT VANCEBORO ME	1069.6	212	91.23
1042500	KENNEBEC RIVER AT THE FORKS ME	4118.1	418	78.13
1021000	ST. CROIX RIVER AT BARING ME	3558.6	138	91.33
1046500	KENNEBEC RIVER AT BINGHAM ME	7031.8	359	80.36
1054500	ANDROSCOGGIN RIVER AT RUMFORD ME	5358.7	380	87.70
1022500	NARRAGUAGUS RIVER AT CHERRYFIELD ME	587.9	96	108.53
1065500	OSSIPEE RIVER AT CORNISH ME	1170.6	151	108.83
1064140	PRESUMPSCOT RIVER NEAR WEST FALMOUTH ME	1548.8	132	100.38
1066000	SACO RIVER AT CORNISH ME	3348.8	329	104.52
1144500	CONNECTICUT RIVER AT WEST LEBANON NH	10598.2	281	80.39
1154500	CONNECTICUT RIVER AT NORTH WALPOLE NH	14226.8	335	82.65
4293500	MISSISQUOI RIVER NEAR EAST BERKSHIRE VT	1240.6	255	78.00
1129500	CONNECTICUT RIVER AT NORTH STRATFORD NH	2069.4	584	75.86
4292500	LAMOILLE RIVER AT EAST GEORGIA VT	1776.7	240	82.88
4290500	WINOOSKI RIVER NEAR ESSEX JUNCTION VT	2703.9	178	78.71
1131500	CONNECTICUT RIVER NEAR DALTON NH	3921.2	898	76.91
1135500	PASSUMPSIC RIVER AT PASSUMPSIC VT	1129.2	275	75.33
4284000	JAIL BRANCH AT EAST BARRE VT	100.7	411	73.17
1138500	CONNECTICUT RIVER AT WELLS RIVER VT	6847.9	517	87.52
4282500	OTTER CREEK AT MIDDLEBURY VT	1626.5	308	73.55
1076500	PEMIGEWASSET RIVER AT PLYMOUTH NH	1610.9	422	106.95
1144000	WHITE RIVER AT WEST HARTFORD VT	1787.1	316	80.26
1150500	MASCOMA RIVER AT MASCOMA NH	396.2	318	69.24

ID	NAME	WATERSHED AREA KM^2	EST ELEV (M)	RUNOFF (CM)
1081000	WINNIPESAUKEE RIVER AT TILTON NH	1219.8	155	90.01
1153000	BLACK RIVER AT NORTH SPRINGFIELD VT	409.2	403	98.27
1089000	SOUCOOK RIVER NEAR CONCORD NH	198.9	171	84.91
1085500	CONTOOCOOK R BL HOPKINTON DAM AT W HOPKINTON NH	1105.9	242	84.42
1161000	ASHUELOT RIVER AT HINSDALE NH	1087.8	275	87.17
4216418	TONAWANDA CREEK AT ATTICA NY	199.1	475	61.92
4232046	THOMAS CREEK (BOCES) AT FAIRPORT NY	73.8	139	28.93
4232040	IRONDEQUIOT CREEK NEAR PITTSFORD NY	114.9	176	43.12
4217750	MURDER CR NR AKRON NY	152.2	268	48.00
4245236	MEADOW BROOK AT HURLBURT RD SYRACUSE NY	7.5	205	25.80
1387400	RAMAPO RIVER AT RAMAPO NY	224.5	231	113.03
1434025	BISCUIT BROOK AB PIGEON BROOK AT FROST VALLEY NY	9.8	845	111.68
3013000	CONEWANGO CREEK AT WATERBORO NY	751.1	424	84.93
4213500	CATTARAUGUS CREEK AT GOWANDA NY	1129.2	473	75.48
4218518	ELLICOTT CREEK BELOW WILLIAMSVILLE NY	211.3	240	68.91
4216200	SCAJAQUADA CREEK AT BUFFALO NY	39.8	207	61.39
4215000	CAYUGA CREEK NR LANCASTER NY	249.6	316	61.56
4214500	BUFFALO CREEK AT GARDENVILLE NY	367.7	375	71.19
4223000	GENESEE RIVER AT PORTAGEVILLE NY	2548.5	488	64.23
4227000	CANASERAGA CREEK AT SHAKERS CROSSING NY	867.6	473	40.05
4232050	ALLENC REEK NEAR ROCHESTER NY	77.9	151	48.36
4229500	HONEOYE CR AT HONEOYE FALLS NY	507.6	461	27.27
4224775	CANASERAGA CREEK ABOVE DANSVILLE NY	230.2	443	45.79
1524500	CANISTEO R BELOW CANACADEA CR @ HORNELL NY	409.2	416	50.67
1529500	COHOCTON RIVER NEAR CAMPBELL NY	1217.3	416	48.15
1520500	TIOGA RIVER AT LINDLEY NY	1996.8	471	59.02
4232482	KEUKA LAKE OUTLET AT DRESDEN NY	536.1	273	42.34
4234000	FALL CREEK NEAR ITHACA NY	326.3	423	65.45
4240010	ONONDAGA CREEK AT SPENCER ST SYRACUSE NY	284.9	156	55.82
4240100	HARBOR BROOK AT SYRACUSE NY	25.9	232	32.33
1509000	TIOUGHNIOGA RIVER AT CORTLAND NY	756.2	540	64.87
1512500	CHENANGO RIVER NEAR CHENANGO FORKS NY	3840.9	487	63.11
1336000	MOHAWK RIVER BELOW DELTA DAM NEAR ROME NY	388.5	392	86.94

ID	NAME	WATERSHED AREA KM^2	EST ELEV (M)	RUNOFF (CM)
1505000	CHENANGO RIVER AT SHERBURNE NY	681.1	421	56.54
1502500	UNADILLA RIVER AT ROCKDALE NY	1346.8	409	59.51
1500500	SUSQUEHANNA RIVER AT UNADILLA NY	2543.3	419	54.38
1423000	WEST BRANCH DELAWARE RIVER AT WALTON NY	859.8	579	67.53
1346000	WEST CANADA CREEK AT KAST BRIDGE NY	1440.0	274	92.58
1348000	EAST CANADA CREEK AT EAST CREEK NY	753.6	416	85.85
1420500	BEAVER KILL AT COOKS FALLS NY	624.1	632	89.17
1362198	ESOPUS CREEK AT SHANDAKEN NY	154.6	538	98.24
1367500	RONDOUT CREEK AT ROSENDALE NY	999.7	287	77.49
1372500	WAPPINGER CREEK NEAR WAPPINGERS FALLS NY	468.7	123	69.77
1387450	MAHWAH RIVER NEAR SUFFERN NY	31.8	147	116.12
1376500	SAW MILL RIVER AT YONKERS NY	66.3	63	103.09
4263000	OSWEGATCHIE RIVER NEAR HEUVELTON NY	2499.3	232	70.86
4267500	RAQUETTE RIVER AT SOUTH COLTON NY	2426.8	644	75.84
4269000	ST REGIS RIVER AT BRASHER CENTER NY	1585.0	442	66.29
1315500	HUDSON RIVER AT NORTH CREEK NY	2051.2	524	82.42
4278300	NORTHWEST BAY BROOK NEAR BOLTON LANDING NY	60.6	373	64.43
1098530	SUDBURY RIVER AT SAXONVILLE MA	274.5	43	82.34
1208013	BRANCH BROOK NR THOMASTONC T	53.8	264	82.93
1208873	ROOSTER RIVER AT FAIRFIELD CT	28.2	57	63.62
1192883	COGINCHAUG RIVER AT MIDDLEFIELD CT	77.1	60	110.69
1195100	INDIAN RIVER NR CLINTON CT	14.7	68	102.05
1184100	STONY BK NR WEST SUFFIELD CT	26.9	71	99.18
1332000	NORTH BRANCH HOOSIC RIVER AT NORTH ADAMS MA	105.9	482	100.38
1331500	HOOSIC RIVER AT ADAMS MA	120.9	323	86.43
1197000	EAST BRANCH HOUSATONIC RIVER AT COLTSVILLE MA	149.1	458	85.06
1168500	DEERFIELD RIVER AT CHARLEMONT MA	934.9	634	113.25
1170000	DEERFIELD RIVER NEAR WEST DEERFIELD MA	1442.6	400	111.20
1171500	MILL RIVER AT NORTHAMPTON MA	139.8	223	97.12
1183500	WESTFIELD RIVER NEAR WESTFIELD MA	1287.2	392	97.25
1171300	FORT RIVER NEAR AMHERST MA	94.2	190	83.97
1166500	MILLERS RIVER AT ERVING MA	963.4	291	96.82
1165300	LAKE ROHUNTA OUTLET NEAR ATHOL MA	52.5	228	96.18

ID	NAME	WATERSHED AREA KM^2	EST ELEV (M)	RUNOFF (CM)
1175500	SWIFT RIVER AT WEST WARE MA	489.5	194	60.98
1173500	WARE RIVER AT GIBBS CROSSING MA	510.2	215	75.84
176000	QUABOAG RIVER AT WEST BRIMFIELD MA	388.5	227	88.31
1172500	WARE RIVER NEAR BARRE MA	142.7	324	90.17
1173000	WARE RIVER AT INTAKE WORKS NEAR BARRE MA	249.4	267	91.71
1123600	QUINEBAUG R BL WESTVILLE DAM NR SOUTHBRIDGE MA	256.4	247	90.27
1124000	QUINEBAUG R AT QUINEBAUG CT	401.4	195	98.83
1124500	LITTLE RIVER NEAR OXFORD MA	67.3	157	105.23
1094400	NORTH NASHUA RIVER AT FITCHBURG MA	164.2	265	91.41
1094500	NORTH NASHUA RIVER NEAR LEOMINSTER MA	284.9	212	93.16
1096000	SQUANNACOOK RIVER NEAR WEST GROTON MA	160.5	129	89.02
1096500	NASHUA RIVER AT EAST PEPPERELL MA	1121.4	100	75.46
1099500	CONCORD R BELOW R MEADOW BROOK AT LOWELL MA	1048.9	62	94.74
1102000	IPSWICH RIVER NEAR IPSWICH MA	323.7	21	96.87
1100600	SHAWSHEEN RIVER NEAR WILMINGTON MA	94.5	47	101.14
1101500	IPSWICH RIVER AT SOUTH MIDDLETON MA	115.2	26	93.82
1102500	ABERJONA RIVER AT WINCHESTER MA	62.4	30	83.46
1104200	CHARLES RIVER AT WELLESLEY MA	546.4	39	74.87
1103500	CHARLES RIVER AT DOVER MA	473.9	61	93.52
1105000	NEPONSET RIVER AT NORWOOD MA	89.8	71	105.38
1105500	EAST BRANCH NEPONSET RIVER AT CANTON MA	70.4	68	100.07
1105870	JONES RIVER AT KINGSTON MA	40.6	28	119.98
1108500	WADING RIVER AT WEST MANSFIELD MA	50.5	72	101.54
1109000	WADING RIVER NEAR NORTON MA	112.1	46	98.01
1109060	THREEMILE RIVER AT NORTH DIGHTON MA	218.3	37	104.36
1109070	SEGREGANSET RIVER NEAR DIGHTON MA	27.4	33	107.41
1112500	BLACKSTONE RIVER AT WOONSOCKET RI	1077.4	67	96.36
1116500	PAWTUXET RIVER AT CRANSTON RI	518.0	109	89.02
1116000	SOUTH BRANCH PAWTUXET RIVER AT WASHINGTON RI	165.2	103	98.95
1117000	HUNT RIVER NEAR EAST GREENWICH RI	59.5	44	122.40
1118000	WOOD RIVER AT HOPE VALLEY RI	187.5	90	111.04
1117350	CHIPUXET RIVER AT WEST KINGSTON RI	25.8	56	113.28
1117420	USQUEPAUG RIVER NEAR USQUEPAUG RI	93.4	65	105.13

ID	NAME	WATERSHED AREA KM^2	EST ELEV (M)	RUNOFF (CM)
1118300	PENDLETON HILL BK NR CLARKS FALLS CT	10.4	113	112.44
1118500	PAWCATUCK RIVER AT WESTERLY RI	764.0	117	101.16
1124151	QUINEBAUG R AT WEST THOMPSON CT	445.4	162	96.69
1119500	WILLIMANTIC RIVER NR COVENTRY CT	313.3	177	97.51
1122000	NATCHAUG R AT WILLIMANTIC CT	450.6	216	89.63
1122500	SHETUCKET R NR WILLIMANTIC CT	1046.3	205	90.77
1184490	BROAD BK AT BROAD BROOK CT	40.1	75	74.11
1190000	FARMINGTON R AT RAINBOW CT	1528.1	332	93.09
1191000	NORTH BRANCH PARK R AT HARTFORD CT	69.4	43	80.34
1189000	PEQUABUCK R AT FORESTVILLE CT	118.6	140	102.46
1186000	WEST BRANCH FARMINGTON R AT RIVERTON CT	339.2	412	95.60
1199000	HOUSATONIC R AT FALLS VILLAGE CT	1642.0	391	83.59
1205600	W BR NAUGATUCK R AT TORRINGTON CT	87.5	338	85.64
1206900	NAUGATUCK R AT THOMASTON CT	258.4	221	94.38
1200500	HOUSATONIC R AT GAYLORDSVILLE CT	2579.6	355	79.98
1204000	POMPERAUG R AT SOUTHBURY CT	194.5	153	95.55
1208500	NAUGATUCK R AT BEACON FALLS CT	673.4	208	106.95
1209700	NORWALK R AT SOUTH WILTON CT	77.7	156	108.78
1208925	MILL R NR FAIRFIELD CT	74.0	106	75.28
1518862	COWANESQUE RIVER AT WESTFIELD PA	234.6	540	58.64
1553700	CHILLISQUAQUE CR NR WASHINGTONVILLE PA	132.8	189	72.64
1449000	LEHIGH RIVER AT LEHIGHTON	1530.6	471	100.93
1547200	BALD EAGLE CR BLW SPRING CR AT MILESBURG PA	686.3	351	72.51
1548000	BALD EAGLE CREEK AT BEECH CREEK STATION PA	1447.8	449	77.47
1549500	BLOCKHOUSE CREEK NEAR ENGLISH CENTER PA	97.6	518	85.11
1431500	LACKAWAXEN RIVER AT HAWLEY PA	751.1	462	79.47
1536000	LACKAWANNA RIVER AT OLD FORGE PA	859.8	333	61.62
1537000	TOBY CREEK AT LUZERNE PA	83.9	356	57.07
1447800	LEHIGH R BLW FRNCS E. WLTR RES NR WHITE HAV PA	751.1	522	101.72
1439500	BUSH KILL AT SHOEMAKERS PA	303.0	394	88.46
1449800	POHOPOCO CR BLW BELTZVILLE DM NR PARRYVILLE PA	249.6	292	79.80
1469500	LITTLE SCHUYLKILL RIVER AT TAMAQUA PA	111.1	372	98.12
1450500	AQUASHICOLA CREEK AT PALMERTON PA	198.6	241	95.80

ID	NAME	WATERSHED AREA KM^2	EST ELEV (M)	RUNOFF (CM)
1451000	LEHIGH RIVER AT WALNUTPORT PA	2302.5	519	100.40
1451500	LITTLE LEHIGH CREEK NEAR ALLENTOWN PA	209.2	124	86.69
1555000	PENNS CREEK AT PENNS CREEK PA	779.5	489	79.88
1379773	GREEN POND BROOK AT PICATINNY ARSENAL NJ	19.8	259	96.52
1379790	GREEN POND BROOK AT WHARTON NJ	32.6	257	111.45
1381900	PASSAIC RIVER AT PINE BROOK NJ	903.9	95	111.22
1399190	LAMINGTON (BLACK) RIVER AT SUCCASUNNA NJ	19.0	258	82.39
1392210	THIRD RIVER AT PASSAIC NJ	30.5	55	88.31
1399525	AXLE BROOK NR POTTERSVILLE NJ	3.1	100	96.44
1396580	SPRUCE RUN AT GLEN GARDNER NJ	31.8	268	93.42
1396660	MULHOCKAWAY CREEK AT VAN SYCKEL NJ	30.5	177	102.92
1403400	GREEN BROOK AT SEELEY MILLS NJ	16.1	98	100.78
1403535	EB STONY BROOK AT BEST LAKE AT WATCHUNG NJ	4.0	98	98.22
1403540	STONY BROOK AT WATCHUNG NJ	14.2	113	100.17
1396001	ROBINSONS BRANCH AT MAPLE AVE AT RAHWAY NJ	55.9	30	83.38
1398107	HOLLAND BROOK AT READINGTON NJ	23.3	61	94.31
1403150	WEST BRANCH MIDDLE BROOK NEAR MARTINSVILLE NJ	5.1	114	87.55
1403160	WEST BRANCH MIDDLE BROOK NEAR SOMERVILLE NJ	9.9	108	84.93
1400300	PETERS BROOK NEAR RARITAN NJ	10.8	30	77.16
1400350	MACS BROOK AT SOMERVILLE NJ	1.9	34	92.30
1401650	PIKE RUN AT BELLE MEAD NJ	13.8	26	92.04
1384000	WANAQUE R AT MONKS NJ	104.6	153	118.71
1387000	WANAQUE R AT WANAQUE NJ	234.1	170	113.23
1382500	PEQUANNOCK R AT MACOPIN INTAKE DAM NJ	164.9	376	109.29
1388000	RAMAPO RIVER AT POMPTON LAKES NJ	414.4	228	110.41
1388500	POMPTON RIVER AT POMPTON PLAINS NJ	919.4	174	85.72
1380000	BEAVER BK AT OUTLET OF SPLITROCK POND NJ	14.2	295	104.77
1380500	ROCKAWAY RIVER ABOVE RESERVOIR AT BOONTON NJ	300.4	186	112.14
1381000	ROCKAWAY RIVER BELOW RESERVOIR AT BOONTON NJ	308.2	179	84.37
1378500	HACKENSACK RIVER AT NEW MILFORD NJ	292.6	42	58.92
1391500	SADDLE RIVER AT LODI NJ	141.4	85	118.16
1399200	LAMINGTON (BLACK) RIVER NEAR IRONIA NJ	28.2	254	94.00
1379500	PASSAIC RIVER NEAR CHATHAM NJ	259.0	90	105.23

ID	NAME	WATERSHED AREA KM^2	EST ELEV (M)	RUNOFF (CM)
1394500	RAHWAY R NR SPRINGFIELD NJ	66.0	122	74.82
1393500	ELIZABETH RIVER AT ELIZABETH NJ	52.3	34	76.53
1395000	RAHWAY R AT RAHWAY NJ	105.9	27	74.75
1396000	ROBINSONS B RAHWAY R AT RAHWAY NJ	55.9	30	83.38
1457000	MUSCONETCONG RIVER NEAR BLOOMSBURY NJ	365.1	267	94.20
1397000	SB RARITAN R AT STANTON NJ	380.7	194	94.58
1402600	ROYCE BROOK TRIBUTARY NEAR BELLE MEAD NJ	3.1	29	110.97
1402000	MILLSTONE RIVER AT BLACKWELLS MILLS NJ	668.2	29	79.83
1405500	SOUTH RIVER AT OLD BRIDGE NJ	245.0	30	95.19
1405400	MANALAPAN BROOK AT SPOTSWOOD NJ	105.4	30	83.41
1399510	UPPER COLD BROOK NEAR POTTERSVILLE NJ	5.6	202	112.06
1443900	YARDS CREEK NEAR BLAIRSTOWN NJ	13.8	300	96.26

APPENDIX B

LONG-TERM AND WATER-YEAR 1984 NCDC PRECIPITATION STATIONS IN THE NORTHEAST UNITED STATES

ID	NAME	LAT	LONG	ELEVATION METERS	PRECIP LT	PRECIP WY84
060128	ANSONIA 1 NE	41 21	73 04	42.67	**	152.37
060299	BARKHAMSTED	41 55	72 57	201.15	119.99	151.79
060806	BRIDGEPORT WSO AP	41 10	73 08	3.04	105.56	131.39
060961	BULLS BRIDGE DAM	41 39	73 29	79.24	114.58	151.43
060973	BURLINGTON	41 48	72 56	155.44	129.74	162.03
061488	COCKAPONSET RANGER STN	41 28	72 31	48.76	126.97	**
061689	COVENTRY	41 48	72 21	146.30	**	160.40
061762	DANBURY	41 23	73 28	155.44	122.35	175.08
062658	FALLS VILLAGE	41 57	73 22	167.63	110.52	125.83
063207	GROTON	41 21	72 03	12.19	123.32	163.20
063451	HARTFORD BRAINARD FLD	41 44	72 39	6.09	109.68	**
063456	HARTFORD WSO AP	41 56	72 41	48.76	112.75	133.91
064488	MANSFIELD HOLLOW LAKE	41 45	72 11	76.19	114.15	165.56
064767	MIDDLETOWN 4 W	41 33	72 43	112.77	127.25	**
065077	MOUNT CARMEL	41 24	72 54	54.86	124.71	166.45
065445	NORFOLK 2 SW	41 58	73 13	408.41	134.82	157.89
065893	NORWALK GAS PLANT	41 07	73 25	12.19	119.13	169.93
066655	PUTNAM LAKE	41 05	73 38	91.43	128.27	**
066966	ROCKY RIVER DAM	41 35	73 26	67.05	115.93	161.65
067002	ROUND POND	41 18	73 32	243.82	125.98	185.06
067157	SAUGATUCK RESERVOIR	41 15	73 21	91.43	124.74	177.62
067373	SHEPAUG DAM	41 43	73 18	256.01	122.17	156.97
067432	SHUTTLE MEADOW RESVR	41 39	72 49	124.96	125.98	166.19
067959	STAFFORD SPRINGS 2	41 57	72 18	140.20	**	149.28
067970	STAMFORD 5 N	41 08	73 33	57.91	**	182.35
068065	STEVENSON DAM	41 23	73 10	18.28	129.57	183.64
068138	STORRS	41 48	72 15	198.11	120.14	**
068436	TORRINGTON	41 48	73 07	176.77	119.94	150.57
069162	WEST HARTFORD	41 45	72 47	85.33	124.64	168.00
069388	WEST THOMPSON LAKE	41 57	71 54	109.72	119.28	151.38
069568	WIGWAM RESERVOIR	41 41	73 09	173.72	117.09	159.84
069775	WOODBURY	41 33	73 14	198.11	116.84	162.18
170275	AUGUSTA FAA AP	44 19	69 48	106.67	107.95	145.80

ID	NAME	LAT	LONG	ELEVATION METERS	PRECIP LT	PRECIP WY84
170355	BANGOR FAA AP	44 48	68 49	48.76	105.71	147.17
170371	BAR HARBOR 3 NW	44 25	68 15	33.52	129.51	**
170480	BELFAST	44 24	69 00	6.09	124.13	172.11
170600	BINGHAM WYMAN DAM	45 04	69 54	121.91	**	133.76
170814	BRASSUA DAM	45 40	69 49	323.07	99.80	**
170833	BRIDGEWATER	46 25	67 51	124.96	**	125.86
170934	BRUNSWICK	43 54	69 56	21.33	115.21	157.43
171175	CARIBOU WSO AP	46 52	68 01	0.00	92.94	111.13
171479	CLAYTON LAKE 2	46 37	69 32	304.79	**	106.71
171628	CORINNA	44 55	69 16	67.05	108.99	137.36
171975	DOVER-FOXCROFT	45 11	69 15	140.20	**	143.26
172238	EAST HIRAM	43 53	70 45	161.54	**	177.04
172426	EASTPORT	44 55	67 00	0.00	111.30	**
172620	ELLSWORTH	44 32	68 26	6.09	117.88	**
172765	FARMINGTON	44 41	70 09	128.00	116.81	149.83
172868	FORT FAIRFIELD 5 NE	46 48	67 46	0.00	100.66	**
172878	FORT KENT	47 15	68 35	0.00	91.74	113.56
173046	GARDINER	44 13	69 47	42.66	112.67	**
173261	GRAND LAKE STREAM	45 11	67 47	88.39	**	141.50
173417	GUILFORD	45 10	69 24	134.11	**	151.31
173588	HARRIS STATION	45 28	69 52	252.97	**	103.07
173892	HOULTON FAA AP	46 07	67 47	0.00	97.97	115.80
173897	HOULTON	46 08	67 50	0.00	94.49	**
174086	JACKMAN	45 38	70 16	359.64	94.18	107.98
174183	JONESBORO	44 39	67 39	0.00	124.61	157.78
174566	LEWISTON	44 06	70 13	54.86	116.23	166.88
174781	LONG FALLS DAM	45 13	70 12	353.55	98.53	127.56
174817	LOVELL	44 07	70 54	121.91	**	142.27
174878	MACHIAS	44 43	67 28	0.00	127.48	**
174927	MADISON	44 48	69 53	79.24	101.19	129.82
175261	MIDDLE DAM	44 47	70 55	444.98	92.43	**
175460	MOOSEHEAD	45 35	69 43	313.92	100.71	**
175675	NEWCASTLE	44 03	69 32	57.91	**	169.49
176430	ORONO	44 54	68 40	36.57	**	129.90

ID	NAME	LAT	LONG	ELEVATION METERS	PRECIP LT	PRECIP WY84
176705	PHILLIPS	44 49	70 21	182.87	**	126.95
176905	PORTLAND WSMO AP	43 39	70 19	18.28	110.54	161.14
176937	PRESQUE ISLE	46 39	68 00	0.00	91.74	**
177037	RANGELEY	44 58	70 39	466.32	**	113.69
177174	RIPOGENUS DAM	45 53	69 11	295.64	99.49	114.83
177325	RUMFORD 1 SSE	44 32	70 32	192.01	111.35	129.84
177479	SANFORD 2 NNW	43 28	70 47	85.34	**	164.52
178353	SPRINGFIELD	45 24	68 10	134.11	**	136.70
178398	SQUA PAN DAM	46 33	68 20	185.91	96.60	120.45
178965	VAN BUREN 2	47 10	67 56	140.20	**	112.01
178974	**	**	**	**	**	141.48
179151	WATERVILLE PUMP STN	44 33	69 39	27.43	105.26	**
179314	WEST BUXTON 2 NNW	43 42	70 37	45.72	**	168.73
179538	WEST PARIS	44 20	70 35	164.58	**	132.89
179593	WEST ROCKPORT 1 NNW	44 12	69 09	115.82	**	191.85
179891	WOODLAND	45 09	67 24	0.00	117.02	133.38
190120	AMHERST	42 23	72 32	45.71	107.85	141.55
190190	ASHBURNHAM	42 39	71 53	362.69	120.60	150.34
190213	ASHFIELD	42 31	72 47	380.98	**	173.76
190408	BARRE FALLS DAM	42 26	72 02	277.35	**	140.92
190510	BECKET 2 SW	42 19	73 07	484.61	**	153.54
190535	BEDFORD	42 29	71 17	48.77	**	155.19
190551	BEECHWOOD	42 14	70 49	18.28	126.26	163.60
190562	BELCHERTOWN	42 17	72 21	170.67	116.89	141.91
190666	BIRCH HILL DAM	42 38	72 07	262.11	99.82	134.39
190736	BLUE HILL WSO	42 13	71 07	192.01	124.82	163.32
190759	BORDEN BROOK RESV	42 08	72 56	338.31	**	156.29
190770	BOSTON WSO AP	42 22	71 02	6.09	111.28	147.37
190801	BOYLSTON	42 21	71 43	192.01	118.69	138.66
190860	BROCKTON	42 03	71 00	24.38	117.65	**
190998	BUFFUMVILLE LAKE	42 07	71 54	152.39	**	151.82
191436	CHESTERFIELD	42 23	72 51	435.84	123.22	153.82
191447	CHESTNUT HILL	42 20	71 09	36.57	115.39	167.59
191561	CLINTON	42 24	71 41	121.91	119.30	148.34

ID	NAME	LAT	LONG	ELEVATION METERS	PRECIP LT	PRECIP WY84
191611	COLRAIN 4 NNW	42 44	72 43	228.59	**	172.11
192026	DUNSTABLE	42 40	71 31	64.00	**	143.64
192107	EAST BRIMFIELD LAKE	42 07	72 08	207.25	**	141.43
192451	EAST WAREHAM	41 46	70 40	6.09	120.73	137.80
192806	FITCHBURG 4 SE	42 33	71 45	100.57	116.28	**
192975	FRAMINGHAM	42 17	71 25	51.81	115.16	143.46
192997	FRANKLIN	42 05	71 25	73.14	121.97	157.35
193052	GARDNER	42 35	71 59	338.31	110.01	143.36
193213	GREAT BARRINGTON AP	42 11	73 24	222.49	**	139.45
193401	HARDWICK	42 21	72 11	301.73	115.09	146.41
193505	HAVERHILL	42 46	71 04	6.09	108.43	157.10
193549	HEATH	42 40	72 49	484.60	128.12	167.36
193624	HINGHAM	42 14	70 55	9.14	**	158.12
193702	HOLYOKE	42 12	72 36	30.47	111.15	133.73
193772	HUBBARDSTON	42 29	72 00	298.68	106.88	**
193876	IPSWICH	42 40	70 52	24.38	119.71	**
193985	KNIGHTVILLE DAM	42 17	72 52	192.01	113.74	149.12
194075	LANESBORO	42 33	73 14	377.93	**	143.43
194105	LAWRENCE	42 42	71 10	18.28	108.10	**
194449	MANSFIELD	42 03	71 12	42.66	121.26	154.79
194711	MIDDLEBORO	41 53	70 55	18.28	119.51	144.68
194744	MIDDLETON	42 36	71 01	27.43	108.92	**
194760	MILFORD	42 10	71 31	85.33	115.70	153.52
195175	NATICK	42 18	71 22	45.72	**	152.15
195246	NEW BEDFORD	41 38	70 56	21.33	111.61	154.20
195285	NEWBURYPORT	42 50	70 55	3.04	114.17	165.96
195306	NEW SALEM	42 27	72 20	274.30	124.79	180.01
195524	NORTHBRIDGE 2	42 07	71 41	97.53	115.47	149.07
196245	PEABODY	42 32	70 59	51.81	**	165.05
196251	PELHAM	42 24	72 24	335.26	117.42	148.34
196262	PEMBROKE	42 01	70 49	21.33	124.54	162.13
196322	PETERSHAM 3 N	42 32	72 11	332.21	107.85	**
196425	PLAINFIELD	42 31	72 55	493.75	121.26	160.78
196486	PLYMOUTH	41 57	70 40	27.43	121.18	**

ID	NAME	LAT	LONG	ELEVATION METERS	PRECIP LT	PRECIP WY84
196699	QUABBIN INTAKE	42 22	72 17	167.63	115.47	145.54
196783	READING	42 31	71 08	27.43	**	161.82
196938	ROCHESTER	41 47	70 55	18.28	125.37	151.87
196977	ROCKPORT 1 ESE	42 39	70 36	24.38	115.42	**
197293	SEGREGANSET	41 50	71 07	12.19	118.75	**
197627	SOUTHBRIDGE 3 SW	42 03	72 05	219.44	126.37	162.69
198046	SPRINGFIELD	42 06	72 35	57.90	113.97	**
198154	STERLING	42 27	71 49	146.29	124.36	155.07
198181	STOCKBRIDGE	42 18	73 20	262.11	111.07	**
198278	SUNDERLAND	42 27	72 33	73.15	**	141.27
198367	TAUNTON	41 54	71 04	6.09	116.26	154.91
198573	TULLY LAKE	42 38	72 13	210.30	108.56	153.14
198757	WALPOLE 2	42 10	71 15	45.72	**	161.37
198793	WARE	42 16	72 15	124.96	112.01	134.24
199191	WESTFIELD	42 07	72 42	67.05	115.01	153.80
199226	WEST GROTON	42 37	71 38	103.63	**	144.53
199316	WEST MEDWAY	42 08	71 26	64.00	**	159.99
199371	WEST OTIS	42 10	73 09	414.50	111.68	**
199780	WINCHENDON 2	42 41	72 03	310.88	**	139.22
199923	WORCESTER WSO AP	42 16	71 52	301.73	120.90	152.76
270100	ALTON	43 26	71 16	243.83	**	148.79
270681	BENTON 5 SW	44 02	71 56	365.74	**	118.08
270690	BERLIN	44 27	71 11	283.45	97.54	126.72
270703	BETHLEHEM	44 17	71 41	420.60	96.82	110.01
270741	BLACKWATER DAM	43 19	71 43	167.63	105.51	157.51
270910	BRADFORD	43 15	71 58	295.64	112.42	144.32
271001	BRISTOL 2	43 35	71 44	179.82	**	147.65
271647	COLEBROOK 2 E	44 54	71 29	316.98	**	106.50
271683	CONCORD WSO AP	43 12	71 30	106.67	92.79	123.04
271950	DEERING	43 05	71 53	307.83	**	153.42
272023	DIXVILLE NOTCH	44 52	71 20	481.56	116.99	113.67
272174	DURHAM	43 09	70 57	21.33	109.80	141.38
272842	ERROL	44 47	71 08	390.12	96.80	**
272999	FIRST CONN LAKE	45 05	71 17	505.94	111.13	111.94

ID	NAME	LAT	LONG	ELEVATION METERS	PRECIP LT	PRECIP WY84
273024	FITZWILLIAM 2 W	42 47	72 11	353.55	112.83	145.29
273182	FRANKLIN FALLS DAM	43 28	71 39	131.05	100.20	144.30
273626	GREENLAND	43 02	70 51	9.14	**	169.42
273850	HANOVER	43 42	72 17	182.87	93.14	125.73
274329	JEFFERSON 4 S	44 22	71 29	371.84	**	103.63
274399	KEENE	42 55	72 16	146.29	102.39	123.37
274475	LAKEPORT	43 33	71 28	170.67	105.38	**
274480	LAKEPORT 2	43 33	71 28	152.39	94.46	**
274556	LANCASTER	44 29	71 35	277.35	**	100.46
274656	LEBANON FAA AIRPORT	43 38	72 19	170.67	88.39	111.53
275013	MACDOWELL DAM	42 54	71 59	295.64	117.86	154.20
275150	MARLOW	43 07	72 12	356.59	96.24	123.83
275211	MASSABESIC LAKE	42 59	71 24	76.19	101.27	**
275400	MILAN 7 NNW	44 40	71 13	359.64	96.80	**
275412	MILFORD	42 49	71 39	91.43	114.30	148.44
275500	MONROE 5 NNE	44 19	72 00	201.16	**	105.21
275532	MOULTONBORO 5 WSW	43 44	71 29	182.87	**	147.83
275639	MOUNT WASHINGTON	44 16	71 18	1907.95	228.40	334.24
275712	NASHUA 2 NNW	42 47	71 29	39.62	109.91	140.72
275868	NEWPORT	43 22	72 11	237.73	97.49	122.61
276550	OTTER BROOK LAKE	42 57	72 14	207.25	**	130.76
276697	PETERBORO 2 S	42 51	71 57	310.88	112.01	138.40
276818	PINKHAM NOTCH	44 16	71 15	612.61	147.07	**
276945	PLYMOUTH 1 E	43 46	71 40	170.67	109.22	**
277967	SOUTH DANBURY	43 30	71 54	283.45	107.16	**
278081	SOUTH LYNDEBORO	42 53	71 47	198.11	114.35	**
278539	SURRY MOUNTAIN LAKE	43 00	72 19	167.63	95.38	133.15
278612	TAMWORTH 3	43 54	71 18	240.78	**	161.34
278972	WEARE	43 05	71 44	219.44	**	155.02
279474	WEST RUMNEY	43 48	71 51	170.67	111.43	139.93
279940	WOODSTOCK	43 59	71 41	219.44	114.73	**
280729	BELVIDERE	40 50	75 05	85.33	115.80	**
280907	BOONTON 1 SE	40 54	74 24	85.33	121.54	169.16
280927	BOUND BROOK 2 W	40 33	74 34	15.24	**	152.91

ID	NAME	LAT	LONG	ELEVATION METERS	PRECIP LT	PRECIP WY84
280978	BRANCHVILLE	41 09	74 45	176.77	111.99	**
281327	CANISTEAR RESERVOIR	41 07	74 30	316.98	**	159.03
281335	CANOE BROOK	40 45	74 21	54.86	123.49	175.97
281582	CHARLOTTEBURG RESERVOIR	41 02	74 26	231.63	129.44	170.51
282023	CRANFORD	40 39	74 18	24.38	**	177.70
282768	ESSEX FELLS SERV BLDG	40 50	74 17	106.67	122.73	**
283029	FLEMINGTON	40 30	74 52	54.86	118.52	**
283516	GREENWOOD LAKE	41 08	74 20	143.24	132.33	174.73
284339	JERSEY CITY	40 44	74 03	42.66	111.18	**
284887	LITTLE FALLS	40 53	74 14	45.71	125.48	181.74
284931	LODI	40 52	74 05	15.24	**	166.42
285003	LONG VALLEY	40 47	74 47	167.63	128.47	178.71
285104	MAHWAH	41 06	74 10	76.20	**	180.31
285503	MIDLAND PARK	40 59	74 09	64.00	128.35	180.62
285769	MORRIS PLAINS 1 W	40 50	74 30	121.91	126.80	183.24
286026	NEWARK WSO AP	40 42	74 10	9.14	107.54	176.07
286055	NEW BRUNSWICK 3 SE	40 28	74 26	27.43	115.57	166.52
286146	NEW MILFORD	40 57	74 02	3.04	110.08	153.77
286177	NEWTON ST PAUL'S ABBEY	41 02	74 48	182.87	111.84	153.97
286460	OAK RIDGE RESERVOIR	41 02	74 30	268.21	130.25	**
287079	PLAINFIELD	40 36	74 24	27.43	123.85	**
287301	POTTERSVILLE 2 NNW	40 44	74 44	112.77	**	187.10
287393	RAHWAY	40 36	74 16	6.09	109.02	165.48
287587	RINGWOOD	41 08	74 16	94.48	118.87	**
288194	SOMERVILLE 3 NW	40 36	74 38	48.76	115.21	152.88
288402	SPLIT ROCK POND	40 58	74 28	243.82	127.36	166.55
288644	SUSSEX 1 SE	41 12	74 36	118.86	115.29	**
289187	WANAQUE RAYMOND DAM	41 03	74 18	76.19	119.74	**
289832	WOODCLIFF LAKE	41 01	74 03	30.47	120.83	176.48
300023	ADDISON	42 06	77 13	313.92	84.73	**
300042	ALBANY WSO AP	42 45	73 48	85.33	90.78	106.71
300063	ALCOVE DAM	42 28	73 56	182.87	97.99	118.26
300085	ALFRED	42 15	77 47	542.51	93.40	122.86
300093	ALLEGANY STATE PARK	42 06	78 45	457.17	111.76	134.26

ID	NAME	LAT	LONG	ELEVATION METERS	PRECIP LT	PRECIP WY84
300183	ANGELICA	42 18	78 01	432.79	86.66	121.67
300220	ARCADE	42 32	78 25	475.46	104.09	124.56
300254	ARKVILLE 2 W	42 08	74 39	399.26	99.44	108.99
300331	**	**	**	**	**	106.22
300343	**	**	**	**	**	100.41
300360	BAINBRIDGE	42 17	75 27	304.78	103.00	**
300379	BALDWINSVILLE	43 09	76 20	115.81	102.34	122.76
300443	BATAVIA	42 59	78 11	271.25	86.28	101.55
300452	BATTENVILLE	43 06	73 26	118.87	**	120.27
300500	BEAVER FALLS	43 53	75 26	225.54	92.63	**
300608	BENNETTS BRIDGE	43 32	75 57	201.15	124.56	147.40
300641	BERLIN 5 S	42 37	73 22	347.46	**	123.80
300668	BIG MOOSE 3 SE	43 48	74 52	536.42	129.90	**
300687	BINGHAMTON WSO AP	42 13	75 59	487.65	93.45	110.90
300766	BOLIVAR	42 04	78 10	481.56	**	117.17
300785	BOONVILLE 2 SSW	43 27	75 21	481.56	146.25	159.33
300817	BRADFORD 1 NW	42 23	77 07	414.50	80.70	**
300870	BREWERTON LOCK 23	43 14	76 12	115.81	106.83	123.70
300929	BROADALBIN	43 03	74 12	256.01	108.23	123.09
300937	BROCKPORT 2 NW	43 15	77 58	0.00	71.96	87.25
301012	BUFFALO WSCMO AP	42 56	78 44	0.00	95.30	120.22
301110	CAMDEN 2 NW	43 22	75 47	164.58	**	139.67
301152	CANANDAIGUA 3 S	42 51	77 17	219.44	78.92	96.49
301160	CANASTOTA	43 05	75 46	124.96	100.10	**
301168	CANDOR	42 14	76 20	274.30	91.14	125.32
301173	CANISTEO 1 S	42 16	77 37	353.55	82.02	**
301185	CANTON 4 SE	44 34	75 07	0.00	90.47	**
301207	CARMEL 1 SW	41 25	73 42	149.34	117.68	**
301265	CAYUGA LOCK 1	42 57	76 44	115.81	87.48	93.19
301387	CHASM FALLS	44 45	74 13	323.07	104.19	**
301401	CHAZY	44 53	73 26	51.81	83.87	**
301413	CHEMUNG	42 00	76 38	246.87	85.78	126.01
301424	CHEPACHET	42 55	75 07	402.32	**	113.26
301436	CHERRY VALLEY 2 NNE	42 49	74 44	414.50	103.96	112.40

ID	NAME	LAT	LONG	ELEVATION METERS	PRECIP LT	PRECIP WY84
301492	CINCINNATUS	42 32	75 54	320.02	107.44	129.74
301521	CLARYVILLE	41 55	74 34	487.66	**	139.50
301580	CLYDE LOCK 26	43 04	76 50	118.86	95.53	114.99
301593	COBLESKILL 2	42 41	74 29	274.31	**	102.54
301664	COLTON 2 N	44 35	74 57	176.77	99.80	**
301708	CONKLINGVILLE DAM	43 19	73 56	246.87	106.96	139.07
301752	COOPERSTOWN	42 42	74 55	365.74	99.77	100.13
301792	CORNING 5 SSW	42 04	77 03	499.85	**	112.17
301799	CORTLAND	42 36	76 11	344.40	104.67	111.58
301966	DANNEMORA	44 43	73 43	408.41	84.23	111.51
301974	DANSVILLE	42 34	77 42	210.30	79.04	108.46
302129	DOBBS FERRY	41 01	73 52	73.14	127.89	190.65
302137	DOLGEVILLE	43 05	74 46	210.30	109.30	**
302169	DOWNSVILLE DAM	42 05	74 58	396.22	**	131.42
302236	EAGLE BRIDGE 2 SE	42 56	73 22	115.82	**	106.60
302277	**	**	**	**	**	98.86
302554	ELIZABETHTOWN	44 13	73 36	182.87	87.30	115.77
302574	ELLENBURG DEPOT	44 54	73 48	262.11	77.52	82.50
302582	ELLENVILLE	41 43	74 24	106.67	115.80	150.37
302610	ELMIRA 2 SE	42 05	76 47	256.01	84.07	120.04
302934	FORT DRUM	44 02	75 46	192.01	**	120.45
303010	FRANKFORT LOCK 19	43 04	75 07	124.96	103.25	118.75
303025	FRANKLINVILLE 1 SSW	42 20	78 28	481.56	100.48	**
303033	FREDONIA	42 27	79 18	231.63	96.49	118.19
303050	FREEVILLE 1 NE	42 31	76 20	320.02	91.26	116.05
303065	FRIENDSHIP 7 SW	42 08	78 14	499.85	**	127.05
303076	FROST VALLEY	41 58	74 33	560.80	137.46	**
303138	GARDINER	41 41	74 09	97.53	**	129.51
303144	GARDNERVILLE	41 21	74 29	140.20	**	135.89
303152	GARNERVILLE	41 13	74 00	57.91	**	175.56
303184	GENEVA RESEARCH FARM	42 53	77 02	219.44	83.59	98.73
303259	GLENHAM	41 31	73 56	85.33	110.26	148.18
303284	GLENS FALLS FARM	43 20	73 44	152.39	106.25	142.44
303294	GLENS FALLS FAA AP	43 21	73 37	97.53	89.43	119.58

ID	NAME	LAT	LONG	ELEVATION METERS	PRECIP LT	PRECIP WY84
303319	GLOVERSVILLE	43 03	74 20	265.16	106.76	114.43
303346	GOUVERNEUR 3 NW	44 21	75 31	128.00	97.23	92.20
303354	GOWANDA PSYCHIATRIC CTR	42 29	78 56	262.12	**	99.64
303360	GRAFTON	42 47	73 28	475.46	111.71	143.81
303365	GRAHAMSVILLE	41 51	74 32	292.59	116.26	**
303444	GREENE	42 19	75 46	280.40	**	113.54
303507	GRIFFISS AIR FORCE BASE	43 14	75 24	149.34	**	114.81
303722	HASKINVILLE	42 25	77 34	499.84	86.77	122.83
303773	HEMLOCK	42 47	77 37	274.30	78.84	**
303851	HIGHMARKET	43 35	75 31	542.51	134.29	149.17
303889	HINCKLEY 2 NE	43 19	75 07	359.64	126.06	**
303961	HOOKER 4 N	43 45	75 44	512.03	140.54	166.98
303970	HOPE	43 18	74 15	268.21	113.39	137.11
303983	HORNELL ALMOND DAM	42 21	77 42	405.36	**	122.89
304025	HUDSON CORRECTIONAL FAC	42 15	73 48	18.29	**	148.13
304102	INDIAN LAKE 2 SW	43 45	74 17	505.94	100.91	**
304174	ITHACA CORNELL UNIV	42 27	76 27	292.59	89.59	115.44
304525	LAKE DELAWARE	42 15	74 54	448.03	108.84	**
304555	LAKE PLACID 2 S	44 15	73 59	591.28	97.51	101.80
304647	LAWRENCEVILLE	44 45	74 39	152.39	84.66	87.68
304731	LIBERTY 1 NE	41 48	74 44	481.56	125.93	138.86
304772	LINDLEY	42 02	77 08	301.74	**	110.64
304791	LITTLE FALLS CITY RES	43 04	74 52	274.30	106.53	**
304796	LITTLE FALLS MILL ST	43 02	74 52	109.72	104.80	**
304808	LITTLE VALLEY	42 15	78 48	481.56	124.56	142.90
304836	LOCKE 2 W	42 40	76 28	365.74	94.28	119.68
304844	LOCKPORT 2 NE	43 11	78 39	0.00	90.68	110.19
304849	LOCKPORT 4 NE	43 12	78 38	134.11	**	107.62
304912	LOWVILLE	43 48	75 29	262.11	101.80	108.61
304944	LYONS FALLS	43 37	75 22	243.82	113.84	**
304996	MALONE	44 51	74 18	268.21	**	88.01
305134	MASSENA FAA AP	44 56	74 51	0.00	83.67	76.78
305171	MAYS POINT LOCK 25	43 00	76 46	121.91	85.29	101.98
305248	MELROSE 1 NE	42 51	73 37	106.67	**	120.17

ID	NAME	LAT	LONG	ELEVATION METERS	PRECIP LT	PRECIP WY84
305310	MIDDLETOWN 2 NW	41 27	74 27	213.35	**	134.52
305334	MILLBROOK	41 51	73 37	249.92	103.12	**
305426	MOHONK LAKE	41 46	74 09	380.98	120.24	147.42
305512	MORRISVILLE 3 S	42 51	75 39	423.65	**	136.80
305597	MOUNT MORRIS 2 W	42 44	77 54	268.21	71.15	**
305635	**	**	**	**	**	107.47
305639	NARROWSBURG 4 SE	41 34	75 01	225.54	**	124.82
305673	NEW ALBION	42 18	78 54	566.90	**	135.97
305679	NEWARK	43 03	77 05	131.05	86.82	**
305751	NEW LONDON LOCK 22	43 13	75 39	121.91	106.38	116.46
305801	N Y CNTRL PK WSFO CI	40 47	73 58	39.62	112.06	**
305821	N Y WESTERLEIGH STAT IS	40 36	74 10	24.38	118.72	**
305869	NORFOLK	44 48	75 00	70.10	**	99.44
305925	NORTH CREEK	43 40	73 54	271.26	**	123.39
306047	NORTH TONAWANDA	43 05	78 45	1853.09	**	122.28
306062	NORTHVILLE	43 14	74 10	243.83	**	128.60
306085	NORWICH	42 32	75 32	310.88	102.31	108.51
306164	OGDENSBURG 4 NE	44 44	75 26	0.00	82.98	**
306184	OLD FORGE	43 43	74 59	548.61	**	137.26
306196	OLEAN	42 05	78 27	432.79	93.93	119.33
306314	OSWEGO EAST	43 28	76 30	106.67	99.82	116.61
306356	OSWEGO 3 WSW	42 05	76 19	246.88	**	116.94
306464	PAVILION	42 53	78 02	286.50	**	116.13
306510	PENN YAN	42 40	77 04	219.44	79.15	**
306538	PERU 2 WSW	44 34	73 34	155.44	73.46	**
306567	PHOENICIA	42 05	74 20	265.16	**	134.16
306623	PISECO	43 27	74 32	527.28	**	165.96
306745	**	**	**	**	**	103.86
306774	PORT JERVIS	41 23	74 41	143.24	109.25	145.80
306820	POUGHKEEPSIE FAA AP	41 38	73 53	48.76	102.01	126.90
306839	PRATTSVILLE 3 N	42 21	74 27	347.46	**	117.50
307129	RIVERBANK	43 36	73 44	228.59	**	128.22
307167	ROCHESTER WSO AP	43 07	77 40	167.63	79.43	103.48
307195	ROCKDALE	42 23	75 24	313.93	**	98.98

ID	NAME	LAT	LONG	ELEVATION METERS	PRECIP LT	PRECIP WY84
307210	ROCK HILL 3 SW	41 35	74 37	387.08	**	148.31
307348	SABATTIS 3 NE	44 07	74 40	536.42	106.05	**
307405	SALEM	43 10	73 19	149.34	99.62	98.35
307484	SARATOGA SPRINGS 4 SW	43 02	73 49	94.48	**	135.53
307497	SCARSDALE	40 59	73 48	60.95	120.45	**
307513	SCHENECTADY	42 50	73 55	67.05	90.47	100.13
307705	SHERBURNE 2 S	42 39	75 29	329.16	91.82	103.30
307721	SHOKAN BROWN STATION	41 57	74 12	155.44	122.35	**
307772	SINCLAIRVILLE	42 16	79 16	423.65	**	149.76
307780	SKANEATELES	42 57	76 26	268.21	97.10	**
307799	SLIDE MOUNTAIN	42 01	74 25	807.68	**	167.41
307818	SMITHS BASIN	43 21	73 30	39.62	93.80	**
307842	SODUS CENTER	43 12	77 01	128.00	92.89	**
308058	SOUTH WALES EMERY PARK	42 43	78 36	332.21	109.40	**
308088	SPENCER 1 SW	42 11	76 30	335.26	95.10	**
308160	STAMFORD	42 24	74 38	536.42	**	109.09
308248	STILLWATER RESERVOIR	43 53	75 02	515.08	116.36	**
308322	SUFFERN WATER WORKS	41 07	74 09	82.29	122.50	**
308383	SYRACUSE WSO AP	43 07	76 07	128.00	99.34	101.45
308578	TRENTON FALLS	43 16	75 09	243.82	125.43	137.01
308586	TRIBES HILL	42 57	74 17	91.43	96.24	**
308594	TROUPSBURG 4 NE	42 04	77 29	521.18	**	97.76
308600	TROY LOCK AND DAM 2	42 45	73 41	73.15	**	128.04
308625	**	**	**	**	**	112.52
308627	TULLY-HEIBERG FOREST	42 46	76 05	579.09	**	133.99
308631	TUPPER LAKE SUNMOUNT	44 14	74 26	512.03	98.09	**
308670	UNADILLA 2 N	42 21	75 19	451.08	**	111.00
308737	UTICA FAA AP	43 09	75 23	216.39	110.34	122.96
308746	VALATIE 1 N	42 26	73 41	91.44	**	123.01
308833	VESTAL	42 03	76 03	454.13	**	120.07
308936	WALTON	42 10	75 08	377.93	**	120.60
308944	WANAKENA RANGER SCHOOL	44 09	74 54	460.22	107.04	**
308962	**	**	**	**	**	126.24
308987	WATERLOO	42 54	76 52	137.15	81.10	86.41

ID	NAME	LAT	LONG	ELEVATION METERS	PRECIP LT	PRECIP WY84
309000	WATERTOWN	43 58	75 52	152.39	102.95	**
309005	WATERTOWN FAA AP	44 00	76 01	97.53	**	95.53
309055	WELLESLEY ISLAND	44 18	76 02	85.34	**	99.75
309140	WESTCHESTER CO AP	41 04	73 41	134.11	**	192.46
309189	WESTFIELD 3 SW	42 17	79 36	323.07	108.33	127.71
309250	WEST MILTON	43 02	73 56	134.11	**	124.84
309292	WEST POINT	41 23	73 58	97.53	123.85	**
309303	WEST SAND LAKE 2 S	42 37	73 36	195.06	**	125.35
309389	WHITEHALL	43 33	73 24	36.57	93.29	113.87
309425	WHITESVILLE	42 02	77 46	524.23	**	124.61
309437	WHITNEY POINT	42 21	75 58	316.98	**	109.42
309507	WILSON 2 NE	43 19	78 48	0.00	74.83	87.81
309516	WINDHAM 2 E	42 18	74 13	524.23	**	124.08
309533	WISCOY 1 E	42 30	78 04	347.46	**	105.64
309544	WOLCOTT 3 NW	43 15	76 52	121.91	97.71	**
309670	YORKTOWN HEIGHTS 1 W	41 16	73 48	204.21	**	177.04
360106	ALLENTOWN WSO AP	40 39	75 26	118.86	112.55	157.86
360457	BEAR GAP	40 50	76 30	274.30	105.82	125.65
360629	BETHLEHEM	40 37	75 23	73.14	108.84	**
361212	CANTON	41 39	76 51	353.55	**	129.82
361301	CEDAR RUN	41 31	77 27	243.82	104.67	**
361480	CLARENCE	41 03	77 56	423.65	99.39	126.90
361505	CLAUSSVILLE	40 37	75 39	204.20	118.29	159.79
361806	**	**	**	**	**	120.78
361833	COVINGTON 2 WSW	41 44	77 07	533.37	**	107.14
362013	DANVILLE	40 58	76 37	140.20	101.70	133.10
362644	ENGLISH CENTER	41 26	77 17	268.21	97.87	**
363056	FREELAND	41 01	75 54	579.09	118.08	**
363130	GALETON	41 44	77 38	417.55	100.76	120.98
363394	GOULDSBORO	41 15	75 27	576.04	117.70	145.36
363758	HAWLEY	41 29	75 10	268.21	100.41	121.29
364008	HOLLISTERVILLE	41 23	75 26	417.55	108.92	139.75
364043	HONESDALE 4 NW	41 37	75 19	429.74	109.27	134.75
364672	KRESGEVILLE 2 W	40 54	75 32	252.97	122.15	161.87

ID	NAME	LAT	LONG	ELEVATION METERS	PRECIP LT	PRECIP WY84
364727	LAKE MINISINK	41 13	75 03	414.51	**	138.91
364934	LEHIGHTON	40 50	75 43	176.77	120.50	**
364972	LE ROY	41 41	76 43	316.97	88.90	128.24
365109	LOCK HAVEN SEW PLT	41 07	77 27	173.73	**	126.95
365160	LONG POND 2 W	41 03	75 30	566.90	130.12	158.72
365344	MAHANOY CITY 2 N	40 50	76 08	521.18	**	144.30
365470	MATAMORAS	41 22	74 42	121.91	112.29	**
365790	MILLHEIM	40 53	77 29	326.12	104.11	179.45
365817	MILLVILLE 2 SW	41 06	76 34	262.11	101.96	117.48
365915	MONTROSE	41 50	75 52	475.46	107.04	118.34
366326	NEW TRIPOLI 4 E	40 41	75 41	210.30	120.80	**
366622	ORWELL 2 NW	41 55	76 18	487.66	**	118.19
366689	PALMERTON	40 48	75 37	124.96	109.07	132.26
366762	PAUPACK 2 WNW	41 24	75 14	414.50	105.13	128.60
367029	PLEASANT MOUNT 1 W	41 44	75 27	548.61	120.50	**
367103	**	**	**	**	**	127.61
367310	**	**	**	**	**	132.23
367409	RENOVO	41 20	77 44	201.16	**	133.40
367727	RUSHVILLE	41 47	76 07	265.16	92.10	113.74
367730	SABINSVILLE 3 SE	41 50	77 28	60.96	**	115.57
367931	SELINSGROVE 2 S	40 46	76 52	128.01	**	119.94
367978	SHAMOKIN	40 48	76 33	234.68	107.80	135.26
368057	SHICKSHINNY 3 N	41 12	76 08	243.83	**	136.02
368145	SINNEMAHONING	41 19	78 06	249.92	102.69	145.42
368469	STEVENSON DAM	41 24	78 01	283.45	**	125.81
368596	STROUDSBURG	41 00	75 11	146.29	121.89	154.15
368692	SUSQUEHANNA	41 57	75 36	277.35	99.62	110.64
368758	TAMAQUA	40 47	75 59	283.45	128.80	166.09
368763	TAMAQUA 4 N DAM	40 51	75 59	341.35	124.99	163.22
368893	TOBYHANNA	41 11	75 25	594.33	**	147.88
368905	TOWANDA 1 ESE	41 45	76 25	228.58	86.31	**
368959	TROY 1 NE	41 47	76 47	338.31	88.27	119.48
369408	WELLSBORO 3 S	41 42	77 16	566.90	85.39	111.30
369702	WILKES-BARRE	41 14	75 53	201.15	95.86	109.55

ID	NAME	LAT	LONG	ELEVATION METERS	PRECIP LT	PRECIP WY84
369705	W BARRE SCRANT WSO AP	41 20	75 44	283.45	89.10	112.52
369728	WILLIAMSPORT WSO AP	41 15	76 55	158.48	104.85	127.64
374266	KINGSTON	41 29	71 32	326.12	123.16	175.95
375215	NEWPORT	41 31	71 19	6.10	**	158.45
375270	NORTH FOSTER 1 E	41 51	71 44	192.01	**	157.76
376698	PROVIDENCE WSO AP	41 44	71 26	15.23	115.11	159.00
430277	BALL MOUNTAIN LAKE	43 07	72 48	344.41	**	153.64
430499	BELLOWS FALLS	43 08	72 27	91.43	102.62	122.63
430661	BETHEL 4 N	43 53	72 38	201.16	**	129.36
431081	BURLINGTON WSO AP	44 28	73 09	100.57	85.57	112.17
431213	CANAAN	45 00	71 32	316.98	**	97.74
431243	CAVENDISH	43 23	72 36	243.82	109.98	**
431360	CHELSEA	43 59	72 27	243.82	93.12	118.24
431433	CHITTENDEN	43 42	72 57	329.16	106.86	123.22
431580	CORNWALL	43 57	73 13	149.34	86.36	105.28
431786	DORSET 1 S	43 15	73 06	298.68	118.87	**
432769	ENOSBURG FALLS	44 55	72 49	128.00	104.93	**
433341	GILMAN	44 25	71 43	259.06	85.04	**
434052	HUNTINGTON CENTER	44 17	72 58	213.35	**	112.32
434747	LUDLOW	43 24	72 43	365.74	**	150.90
434882	MANCHESTER	43 10	73 04	262.12	**	145.03
435278	MONTPELIER FAA AP	44 12	72 34	344.40	86.21	99.21
435416	MOUNT MANSFIELD	44 32	72 49	1203.90	**	199.19
435492	NEWFANE	43 00	72 38	128.00	110.92	**
435542	NEWPORT	44 56	72 12	234.68	101.45	104.60
435740	NORTHFIELD 3 SSE	44 06	72 37	429.75	**	122.28
436335	PERU	43 15	72 54	508.99	129.11	177.11
436500	POWNAL 1 NE	42 47	73 13	347.46	**	131.29
436761	READSBORO 1 SE	42 45	72 56	341.35	125.10	**
436893	ROCHESTER	43 51	72 48	252.97	110.16	142.01
436995	RUTLAND	43 36	72 58	188.96	88.67	114.73
437032	SAINT ALBANS RADIO	44 50	73 05	118.87	**	127.97
437054	SAINT JOHNSBURY	44 25	72 01	213.34	92.48	109.52
437098	SALISBURY	43 56	73 06	128.00	94.49	**

ID	NAME	LAT	LONG	ELEVATION METERS	PRECIP LT	PRECIP WY84
437152	SEARSBURG STATION	42 52	72 55	475.46	135.36	166.57
437607	SOUTH HERO	44 38	73 18	335.26	**	88.75
437612	SOUTH LINCOLN	44 04	72 58	615.67	**	138.13
437617	SOUTH LONDONDERRY	43 11	72 49	320.02	108.94	**
437646	SOUTH NEWBURY	44 03	72 05	143.24	87.66	**
438556	UNION VILLAGE DAM	43 48	72 16	140.20	89.79	109.80
438600	VERNON	42 46	72 31	70.10	110.57	**
438755	WARDSBORO 1 SW	43 02	72 48	423.65	**	162.18
438815	WATERBURY 2 SSE	44 19	72 45	231.64	**	121.92
439099	WEST BURKE	44 39	71 59	274.30	103.48	115.09
439735	WHITINGHAM 1 W	42 48	72 55	426.69	130.38	160.15
439984	WOODSTOCK 2 WSW	43 37	72 33	228.58	100.15	131.85

APPENDIX C

ESTIMATED AND GAGED RUNOFF FOR THE WITHHELD USGS GAGE SITES

		GAGE84		MNLTET		MNLTRP		REG_R		MN84RP	
ID	GAGED RUNOFF	EST RUNOFF	INT ERROR	EST RUNOFF	INT ERROR	EST RUNOFF	INT ERROR	EST RUNOFF	INT ERROR	EST RUNOFF	INT ERROR
1011000	78.6	83.2	4.6	70.7	-7.9	71.2	-7.4	75.9	-2.6	75.7	-2.9
1010000	91.3	86.4	-4.9	75.5	-15.8	76.1	-15.2	78.8	-12.5	78.4	-12.8
1137500	110.7	130.7	20.0	200.8	90.1	152.2	41.5	162.5	51.8	157.3	46.6
1073000	89.8	88.6	-1.2	86.6	-3.2	76.7	-13.1	82.7	-7.1	86.3	-3.5
4286000	74.5	81.8	7.3	80.9	6.5	81.5	7.0	81.5	7.0	81.5	7.0
4288000	87.9	77.2	-10.6	76.0	-11.8	75.3	-12.5	77.1	-10.7	76.8	-11.1
1141500	76.2	86.5	10.3	66.7	-9.5	67.0	-9.1	79.3	3.1	77.8	1.6
1152500	79.8	94.8	15.1	75.3	-4.5	70.9	-8.8	91.6	11.8	81.6	1.8
1170100	105.0	110.0	5.0	126.5	21.5	104.1	-0.9	107.3	2.3	111.7	6.7
1168151	118.3	107.8	-10.5	122.0	3.7	102.9	-15.4	107.6	-10.7	108.2	-10.1
1196500	107.1	111.0	3.9	116.6	9.5	104.5	-2.6	111.0	3.9	114.7	7.6
1187300	95.9	96.5	0.6	107.6	11.7	96.5	0.6	93.9	-2.0	100.8	4.9
1180500	104.1	93.6	-10.5	102.2	-1.9	95.9	-8.2	93.6	-10.5	97.9	-6.2
1179500	109.3	98.3	-11.0	113.3	4.0	97.5	-11.8	98.4	-10.9	102.6	-6.7
1110000	86.0	90.6	4.6	91.3	5.3	79.8	-6.2	87.4	1.4	90.2	4.2
1105730	101.6	112.7	11.1	107.6	6.0	98.8	-2.8	111.8	10.3	103.8	2.3
4231000	41.7	39.1	-2.6	52.0	10.3	48.7	7.0	41.9	0.2	47.1	5.5
1523500	60.8	56.1	-4.7	68.7	7.9	61.4	0.6	60.6	-0.2	62.3	1.5
4243500	58.6	72.6	14.0	83.2	24.6	64.5	5.9	76.3	17.7	61.3	2.7
1350200	62.8	55.8	-7.0	56.6	-6.2	55.9	-6.9	55.8	-7.0	55.3	-7.5
1365500	76.1	98.8	22.7	94.3	18.2	76.0	-0.1	96.8	20.7	80.9	4.8
1542810	82.3	81.6	-0.7	84.8	2.5	81.6	-0.7	81.8	-0.5	81.7	-0.6
1552000	85.0	90.5	5.5	90.4	5.4	90.6	5.6	90.6	5.6	90.7	5.7
1537500	42.6	65.6	23.0	66.1	23.5	61.4	18.8	62.7	20.1	65.7	23.1
1447680	122.7	95.2	-27.5	100.6	-22.1	86.0	-36.7	95.2	-27.5	93.4	-29.3
1451800	93.1	91.5	-1.6	100.6	7.5	79.9	-13.2	91.9	-1.2	88.4	-4.7
1391000	129.0	116.9	-12.1	114.3	-14.7	108.3	-20.7	112.4	-16.6	112.0	-17.0
1059000	93.3	101.2	7.9	98.5	5.2	94.3	0.9	94.2	0.9	97.0	3.7
1064140	100.4	90.6	-9.8	91.7	-8.6	89.2	-11.2	90.0	-10.4	90.3	-9.7
1144500	80.4	98.6	18.2	71.2	-9.1	71.4	-9.0	73.3	-7.1	76.9	-3.5
1076500	107.0	97.3	-9.7	87.8	-19.1	78.5	-28.4	81.0	-25.9	90.0	-16.9
4223000	64.2	64.2	0.0	72.6	8.4	63.5	-0.8	59.7	-4.6	66.8	2.6
1346000	92.6	80.7	-11.9	92.2	-0.4	84.5	-8.1	77.0	-15.6	88.5	-4.1

		GAGE84		MNLTET		MNLTRP		REG_R		MN84RP	
ID	GAGED RUNOFF	EST RUNOFF	INT ERROR	EST RUNOFF	INT ERROR	EST RUNOFF	INT ERROR	EST RUNOFF	INT ERROR	EST RUNOFF	INT ERROR
1362198	98.2	102.7	4.4	102.3	4.0	81.7	-16.6	97.0	-1.2	86.7	-11.5
1367500	77.5	107.3	29.8	103.3	25.8	91.1	13.6	96.0	18.5	96.1	18.6
1372500	69.8	88.1	18.3	84.0	14.2	76.8	7.1	77.6	7.8	82.5	12.8
4263000	70.9	63.8	-7.0	63.3	-7.6	62.2	-8.7	68.1	-2.8	69.8	-1.0
1166500	96.8	94.5	-2.3	90.2	-6.6	83.4	-13.4	86.8	-10.0	90.8	-6.0
1172500	90.2	88.0	-2.2	93.4	3.2	86.9	-3.3	90.8	0.6	91.7	1.5
1099500	94.7	83.0	-11.7	82.7	-12.0	82.7	-12.0	82.9	-11.9	82.9	-11.8
1105000	105.4	96.7	-8.6	102.0	-3.4	85.3	-20.0	95.6	-9.8	96.7	-8.7
1109000	98.0	102.5	4.5	101.7	3.7	99.0	1.0	101.9	3.9	101.5	3.5
1518862	58.6	62.4	3.8	67.3	8.7	61.9	3.3	62.4	3.8	63.8	5.1
1447800	101.7	94.9	-6.8	95.6	-6.1	95.4	-6.3	94.8	-6.9	95.9	-5.8
1379773	96.5	107.4	10.9	108.5	12.0	107.3	10.8	107.5	10.9	107.1	10.6
1392210	88.3	89.5	1.2	119.8	31.5	91.3	3.0	89.8	1.5	106.4	18.1
1398107	94.3	93.7	-0.6	93.6	-0.7	93.8	-0.5	93.8	-0.5	93.7	-0.6
1379500	105.2	97.8	-7.4	97.8	-7.4	97.8	-7.4	97.8	-7.4	97.6	-7.6
1393500	76.5	90.6	14.1	96.5	20.0	86.5	10.0	85.5	9.0	92.3	15.7
1457000	94.2	97.0	2.8	100.8	6.6	85.9	-8.3	91.1	-3.1	94.6	0.4